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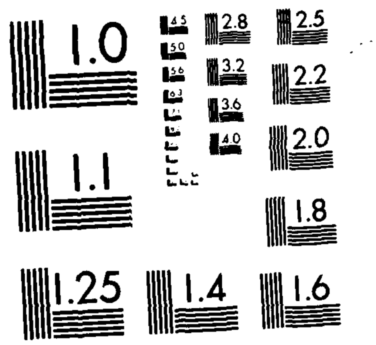
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PLANNING AID REPORT

Evaluation of Salinity-Related Habitat Impacts in the Lower Chesapeake Bay and James River for the Norfolk Harbor and Channels Deepening Study

Prepared for

U.S. Army Corps of Engineers
Norfolk District

Prepared by

U.S. Department of the Interior
Fish and Wildlife Service
Gloucester Point, Virginia

and the

National Coastal Ecosystems Team
Fish and Wildlife Service
Slidell, Louisiana

October, 1984

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Changes in salinities associated with the deepening will result in subtle shifts in habitat primarily in the oligo- to mesohaline section of the James River. These shifts are quite small and there should be no discernable ecosystem changes according to report. Accompanying maps show effects of salinity changes on distribution of various organisms within the Hampton Roads estuarine system.

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The drawings for this set of reports (55 volumes) of the Norfolk Disposal Site Final Environmental Impact Study & Appendix 1 & 2, may be obtained from: U. S. Army Corps of Engineers, Norfolk District, 803 Front Street, Norfolk, VA 23510-1096
Per Mr. James Melchor, Army Corps of Engineers

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC

UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
acres	0.4047	hectares
cubic feet per second	0.0283	cubic meters per second
feet	0.3048	meters
feet per second	0.3048	meters per second

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

APPENDIX A

Description of Study Species

APPENDIX B

Average Seasonal Salinities from the Corps of Engineers Hydraulic Model Test

INTRODUCTION

The Corps of Engineers' Navigation Study

The U.S. Army Corps of Engineers was authorized by Congress in 1969 to undertake a study of the feasibility of deepening the federal navigation channels in the lower Chesapeake Bay and Norfolk Harbor to accommodate deep-draft bulk cargo vessels. In its Feasibility Report on the study (U.S. Army Corps of Engineers, 1980), the Norfolk District recommended the following improvements to the channels and anchorages:

a. Increasing the depth of Thimble Shoal Channel from 45 to 55-feet below mean low water over its existing 1,000-foot width.

b. Increasing the depth of Norfolk Harbor Channel from 45 to 55-feet below mean low water over its existing 800 to 1,500-foot width to the coal terminal at Lamberts Point.

c. Increasing the depth of the channel to Newport News from 45 to 55-feet below mean low water over its existing 800-foot width to the coal terminal at Newport News.

d. Dredging a new channel, referred to as the Atlantic Ocean Channel, off Virginia Beach to a depth of 57-feet below mean low water and a width of 1,000 feet over a length of 10.6-miles.

e. Constructing three fixed-mooring anchorage facilities with a depth of 55-feet, each capable of accommodating two large vessels simultaneously.

f. Increasing the depth of the Elizabeth River and the Southern Branch of the Elizabeth River between Lamberts Point (river mile 9) and the Norfolk and Western Railway Bridge (river mile 15) from 40 to 45-

feet below mean low water over its existing 375 to 750-foot width.

g. Increasing the depth of the Southern Branch of the Elizabeth River between the Norfolk and Western Railway Bridge (river mile 15) and the U.S. Routes 460 and 13 highway crossing (river mile 17.5) from 35 to 40-feet below mean low water over its existing 250 to 500-foot width, and providing a new 800-foot turning basin at the terminus of the channel improvement.

The Chief of Engineers concurred with the Norfolk District's recommendations. However, based on the recommendations of the Fish and Wildlife Service and the Department of the Interior, the Corps undertook an evaluation of the potential environmental impacts that could occur as a result of the deepening project. Therefore, in October 1981, the Norfolk District contracted the U.S. Army Engineer Waterways Experiment Station (WES) to investigate the possible hydrodynamic changes in the Chesapeake Bay using the Corps' hydraulic model located at Matapeake, Maryland. The study was designed to determine what changes in tidal elevations, current velocities, and salinities could be attributed to the proposed channel deepening project. The results of that study are presented in the report Norfolk Harbor and Channels Deepening Study, Physical Model Results (Richards and Morton, 1983).

Purpose of This Study

The major potential environmental impacts associated with the channel deepening project include the direct loss of habitat associated with the dredging operation, habitat impacts associated with the disposal of the dredged material, and habitat changes due to changes in the hydrodynamics of the Chesapeake Bay. The first two types of impacts are being evaluated as part of a joint study by the Norfolk District, Old Dominion University and the Fish and Wildlife Service, and will be reported on after the completion of baseline field studies. The purpose of the present study is to identify and evaluate potential impacts to the fish and wildlife resources of the Chesapeake Bay that could occur due to changes in salinities, tidal amplitudes and current velocities resulting from the deepening project. This has been accomplished using the results of the Corps' hydraulic model test and a computer-based system to predict changes in the habitat of selected organisms.

METHODS

Estuaries, such as the Chesapeake Bay, are complex ecosystems in which a variety of factors interact to provide the habitat for the large number of species that utilize these areas for one or more life stages. Most of these interactions are not completely known and to predict with accuracy how a change in any one factor may influence the entire ecosystem is a question that has only recently been raised and, to a large extent, remains unanswered. Major natural events such as droughts or hurricanes provide a living experiment that allows these interactions to be studied. However, the evaluation of man-made changes in the physical characteristics of the Bay is difficult because the natural variations are not well known. The present study was undertaken based on the premise that potential salinity changes are one of the most likely results of a channel deepening project and one which, to a reasonable extent, can be predicted with existing technology. However, it is acknowledged that until a baywide ecosystem model is developed (if it is indeed possible), a study such as this provides, at best, a limited evaluation of the extent of man's impact on the estuary.

In determining how best to evaluate potential salinity changes from the Norfolk Harbor deepening project, the Service looked for any other ecosystem-based evaluations that had been undertaken in the Chesapeake Bay. The only similar study is the Chesapeake Bay Low Freshwater Inflow Study which was conducted by the Baltimore District Corps of Engineers as part of the larger Chesapeake Bay Study, authorized by Congress in 1965. The Service was a participant in the Low Freshwater Inflow Study and determined that the assessment methodology utilized in that study was appropriate for use in the Norfolk

Harbor Deepening Study. However, the Service utilized the computer-based Map Overlay Statistical System (MOSS) to conduct our assessment, which was not done in the Baltimore District's study. The following is an explanation of the methodologies and data sources that have been utilized in this study.

Development of Assessment Methodology

As stated, this study utilized the assessment methodology that was developed in the Baltimore District's Chesapeake Bay Low Freshwater Inflow Study. Rather than restate the detailed explanation of the development of that methodology, this report will explain the methodology in general terms. The reader is referred to the Low Freshwater Inflow Study for further explanation (Shea et al., 1980; Mackiernan et al., 1982).

A variety of physical and chemical factors determine a species' distribution within the Chesapeake Bay, including salinity, depth, tidal velocities, net flow, turbulence, turbidity, dissolved oxygen, sediment type, temperature and pollutant levels within the water column and sediments. With respect to the present study, the factors that are most relevant to potential habitat changes <u>and</u> that can be consistently modeled with existing information, are salinity, depth and sediment type. The assessment methodology utilized for this study involves the prediction of how changes in any of these three factors resulting from the deepening study will affect the Bay ecosystem. However, since there is no baywide ecosystem model to predict total system impacts, it is necessary instead to evaluate key species within the Bay and to then extrapolate these results to the ecosystem.

Selection of Study Species

Theoretically, a complete impact evaluation would look at the approximately 2650 species that are thought to exist in the Chesapeake Bay (McErlean et al., 1972). This is impractical both from an economic standpoint and because of limitations on the amount of information available on all of these species. It is therefore necessary to select a number of species that will represent taxa and functional groups from the major habitats and salinity zones. The Low Freshwater Inflow Study (LFIS) grouped the Bay's organisms into seven major categories which reflect both function and habitat. These are as follows:

Phytoplankton - Phytoplankton are microscopic single-celled plants that represent several divisions of algae. These species are generally not free swimming, but are carried within the water column through the action of tides and currents.

Submerged Aquatic Vegetation - These are larger plants that live below the water's surface and are usually rooted. They include flowering plants such as eelgrass (*Zostera marina*) and macroalgae such as sea lettuce (*Ulva lactuca*).

Emergent Aquatic Vegetation - These are rooted plants which are permanently or intermittently flooded and whose leaves extend above the surface of the water. They include the freshwater marshes which have a diversity of species and saltmarshes dominated by saltmarsh cordgrass (*Spartina alterniflora*).

Zooplankton - These are small, pelagic animals from a variety of groups. They include species that are planktonic throughout their life, such as the copepods and species which only spend part of their life as plankton, such as the larvae of fish and crabs.

Benthos - These are animals, mainly invertebrates, that live on the surface of or within the substrate. Some species are benthic oriented but are capable of much movement, such as shrimp and crabs; others are virtually immobile, such as oysters.

Fish - Fish species are grouped into those which feed on benthic organisms and those which feed in the water column.

Wildlife - Many species of birds, amphibians, reptiles and mammals utilize the estuary for feeding, resting and breeding.

In selecting representative species from each of these groups, the LFIS used four major criteria in their screening process including:

1. The amount of information available on the species' life history.
2. The sensitivity of the species to physical variables.
3. The linkage of the species to other species in the Bay ecosystem.
4. The species' importance to human utilization, either commercial or recreational.

The LFIS initially screened 167 candidate species and selected 57 as representative of all the major Bay habitat types. These species, listed in Table 1, were selected based on a weighted ranking system by a team of knowl-

Table 1. Study Species from the Baltimore District Corps of Engineers' Chesapeake Bay Low Freshwater Inflow Study.

PHYTOPLANKTON ASSOCIATIONS	
Winter/Spring Associations	Cyclotella meneghiniana/Melosira granulata tidal freshwater association
	Katodinium rotundatum/Skeletonema costatum oligohaline, low mesohaline association
	Asterionella japonica/Skeletonema costatum mesohaline association
	Nitschia pungens atlantica/Skeletonema costatum/ Chaetoceros spp. polyhaline association
Summer/Fall Associations	Anacystis/Microcystis tidal freshwater association
	Gymnodinium spp./Prorocentrum minimum oligohaline, low mesohaline associations
	Gymnodinium/Chaetoceros/Skeletonema high mesohaline, polyhaline associations

SUBMERGED AQUATIC VEGETATION	
Ceratophyllum demersum	hornwort
Potamogeton	pondweeds
Ruppia maritima	widgeon grass
Zanichellia palustris	horned pondweed
Zostera marina	eelgrass

Table 1. (Cont'd.)

	EMERGENT AQUATIC VEGETATION ASSOCIATIONS	
	Tidal Freshwater Associations	
	Spartina spp. dominant, brackish tidal marsh	
	Juncus roemerianus dominant, brackish tidal marsh	
	ZOOPLANKTON	
Ctenophora	_Mnemiopsis leidyi_	ctenophore
Cnidaria	_Chrysaora quinquecirrha_	sea nettle
Rotifera	_Brachionus calcyiflorus_	rotifer
Crustacea	_Acartia clausi_	copepod
	Acartia tonsa	copepod
	Eurytemora affinis	copepod
	Scottolana canadensis	copepod
	Bosmina longirostris	cladoceran
	Evadne tergestina	cladoceran
	Podon polyphemoides	cladoceran
	BENTHOS	
Annelida	_Limnodrilus hoffmeistgeri_	oligochaete worm
	Heteromastus filiformis	polychaete worm
	Pectinaria gouldii	polychaete worm
	Scolecolepides viridis	polychaete worm

Table 1. (Cont'd.)

BENTHOS, Cont.d

Annelida	Streblospio benedicti	polychaete worm
Mollusca	Urosalpinx cinerea	oyster drill
	Macoma balthica	Baltic macoma
	Mercenaria mercenaria	hard clam
	Mulinia lateralis	coot clam
	Mya arenaria	soft clam
	Rangia cuneata	brackish clam
Crustacea	Ampelisca abdita	amphipod
	Balanus improvisus	barnacle
	Callinectes sapidus	blue crab
	Cyathura polita	isopod
	Gammarus daiberi	amphipod
	Leptocheirus plumulosus	amphipod
	Palaemonetes pugio	grass shrimp

FISH

	Alosa sapidissima	American shad
	Alosa pseudoharengus	alewife
	Brevoortia tyrannus	menhaden
	Anchoa mitchilli	bay anchovy
	Leiostomus xanthurus	spot

Table 1. (Cont'd.)

FISH, Cont'd.

Menidia menidia	Atlantic silverside
Micropogon undulatus	Atlantic croaker
Morone saxatilis	striped bass
Morone americana	white perch
Perca flavescens	yellow perch
WILDLIFE	
Anas platyrhynchos	mallard
Anas rubripes	black duck
Aythya valisineria	canvasback

edgable Bay scientists.

The Service initially proposed to evaluate all of the 57 species from the Low Freshwater Inflow Study for the Norfolk Harbor Deepening Study. However, the costs associated with using the Service's computer-based Map Overlay Statistical System limited the evaluation to 20 species. The 20 species were chosen from the list of 57 based on the same four screening criteria utilized in the LFIS, and are listed in Table 2. Appendix A provides a description of each of the species and the reason for their selection for this study. It was decided that if the evaluation of these 20 species indicated that significant habitat changes would occur as a result of the project, the additional 37 species would also be evaluated in more detail.

Data Sources

The evaluation of the impacts of potential salinity changes was accomplished by mapping the distribution of the 20 species within the study area before and after the deepening project and calculating the changes in habitat for each species. A computer-based geographic information system was used for the analysis. Each species was mapped based on five criteria: 1) life stage; 2) season; 3) salinity; 4) depth; and 5) substrate preference (for benthic species). The following is a description of the data sources used in the evaluation.

Habitat Requirements - The habitat requirements for each of the 20 species were obtained using the information from the LFIS, literature reviews, and discussions with scientists who have worked in the lower Chesapeake Bay. For each species,

Table 2. Study Species Selected for Impact Evaluation for the Norfolk Harbor Deepening Study.

	ZOOPLANKTON	
Cnidaria	Chrysaora quinquecirrha	sea nettle
Crustacea	Acartia clausi	copepod
	Eurytemora affinis	copepod
	Scottolana canadensis	copepod
	BENTHOS	
Annelida	Pectinaria gouldii	polychaete worm
	Scolecolepides viridis	polychaete worm
Mollusca	Urosalpinx cinerea	oyster drill
	Crassostrea virginica	oyster
	Mercenaria mercenaria	hard clam
	Macoma balthica	Baltic macoma
Crustacea	Balanus improvisus	barnacle
	Cyathura polita	isopod
	Ampelisca abdita	amphipod
	Leptocheirus plumulosus	amphipod
	Palaemonetes pugio	grass shrimp
	Callinectes sapidus	blue crab

Table 2. (Cont'd.)

FISH	
Alosa sapidissima	American shad
Brevoortia tyrannus	menhaden
Anchoa mitchilli	bay anchovy
Morone saxatilis	striped bass

the most sensitive life stage and season, salinity tolerances, depth and substrate preferences were determined. This information is shown in Table 3. It should be realized that this information produces a map of a species' "potential" distribution but not necessarily that of its "known" distribution. For example, the habitat requirements of the hard clam (Mercenaria mercenaria) are such that its potential habitat includes much of the lower Chesapeake Bay. However, the species' actual distribution in terms of high densities is much smaller. Similarly, the copepod, Acartia clausi, can be limited in distribution in the lower Bay not by salinity but by predation by zooplankton entering the Bay from the Atlantic Ocean (Grant and Olney, 1979).

The American oyster (Crassostrea virginica) was a species of particular concern because the lower James River contains the largest seed oyster beds within Virginia. Any changes in the distribution of the oyster's predators or diseases resulting from salinity shifts could have a significant impact on the oyster industry in the state. Therefore, in addition to determining the oyster's habitat requirements, the actual location of the State owned oyster beds within the James and lower York and Poquoson Rivers were mapped. These beds, known as the "Baylor Grounds", had been recently surveyed by the Virginia Institute of Marine Science.

Pre- and Post- Project Salinities - The Chesapeake Bay salinities used in the evaluation were obtained from the Corps' hydraulic model study (Richards and Morton, 1983). The Corps' physical model investigation defined the pre-project salinities in the Bay as the "base" condition and the post-project salinities as the "plan" condition. The Corps' terminology will be followed

Table 3. Species' Habitat Requirements Utilized as Mapping Criteria.

Species	Life Stage	Season	Salinity Range (0/00)	Depth Range (feet)	Substrate Type
Zooplankton					
Chrysaora quinquechirra (sea nettle)	Medusa	Summer	5-34	Surface	N/A
	Polyp	Summer	7-20	1-32	All
Acartia clausi (copepod)	Adult	Spring	5-34	Surface	N/A
Eurytemora affinis (copepod)	Adult	Spring	5-15	Surface	N/A
Scottolana canadensis (copepod)	Adult and Copepodites	Summer	1-5	0-Bottom	N/A
Benthos					
Pectinaria gouldii (polychaete worm)	Adult	Spring	15-28	0-Bottom	SM,MS,X
Scolecolepides viridis (polychaete worm)	Adult	Spring	1-15	0-Bottom	All
Urosalpinx cinerea (oyster drill)	Adult	Summer	12.5-34	0-30	All*
Crassostrea virginica (oyster)	Adult	Summer	7.5-34	0-30	All*
Mercenaria mercenaria (hard clam)	Adult and larvae	Summer	17-34	3-49	S,MS

* where suitable hard substrate occurs

Table 3. Species' Habitat Requirements Utilized as Mapping Criteria, Cont'd.

Species	Life Stage	Season	Salinity Range (0/00)	Depth Range (feet)	Substrate Type
Macoma balthica (Baltic macoma)	Adult	Fall	5-18	3-Bottom	M,SM,MS,X
Balanus improvisus (acorn barnacle)	Adult	Summer	5-20	3-Bottom	All*
Cyathura polita (isopod)	Adult	Summer	0.5-12	0-20	All
Ampelisca abdita (amphipod)	Adult	Spring	18-32	3-Bottom	MS,SM,X
Leptocheirus plumulosus (amphipod)	Adult	Spring	1-10	0-Bottom	All
Paleomonetes pugio (grass shrimp)	Adult	Summer	5-20	0-10	All
Callinectes sapidus (blue crab)	Males & Juvenile Females	Summer	5-20	0-30	All
	Adult Females	Summer	10-34	0-30	All
	Adult Females with eggs	Summer	20-34	0-30	All
	Zoea larvae	Summer	23-34	Surface	N/A

* where suitable hard substrate occurs

Table 3. Species' Habitat Requirements Utilized as Mapping Criteria, Cont'd.

Species	Life Stage	Season	Salinity Range (0/00)	Depth Range (feet)	Substrate Type
Finfish					
Alosa sapidissima (American shad)	Juveniles	Summer	0-12	Surface	N/A
Brevoortia tyrannus (menhaden)	Postlarvae and Juveniles	Winter	0.1-5	Surface	N/A
Anchoa mitchilli (bay anchovy)	Eggs and Larvae	Summer	8-26	Surface	N/A
Morone saxatilis (striped bass)	Juveniles	Summer	0-10	Surface	N/A

Key to Substrate Types:

S - Sand
MS - Muddy Sand
SM - Sandy Mud
M - Mud
X - Mixed Sediments
N/A - Not Applicable

in this report. The model utilized an actual 2.5-year weekly stepped hydrograph of the Chesapeake Bay from the period of May 1963 to August 1965, and a 28-lunar day, 56-cycle tide sequence. This time frame represents a drought condition within the Chesapeake Bay. Figure 1 shows the Bay hydrograph over the period of record and indicates how the 1963 to 1965 period compares to the average hydrograph. The results of the Corps' model study indicated that there would be no changes in salinities within the Chesapeake Bay above the York River. This information defined the boundaries for the present study, as shown in Figure 2.

A total of 124 salinity sampling stations are located within the study area, as shown on Map 1 of the map portfolio that accompanies this report. These stations include areas within the channels as well as in the shallows. Up to five salinity measurements were taken at each station. Measurements were taken at the surface (0 to 4 feet), 1/4 of the depth, 1/2 of the depth, 3/4 of the depth, and at the bottom. At the shallow stations only the surface, mid-depth, and bottom measurements were taken. The present study utilized only the surface and bottom salinities from the physical model because most of the selected study species are either bottom dwellers or associated with the surface or near-surface water column, and because the Map Overlay Statistical System did not have a program to interpolate salinities in 3 dimensions (i.e. with depth).

Salinity measurements from the model were taken on the slack after flood for 4 tides out of the tidal cycle (tides 1, 10, 28 and 48), corresponding to the high-spring, mean, low-spring, and neap tides. The accuracy of the testing system utilized by the Corps is ± 0.5 parts per thousand (ppt). The

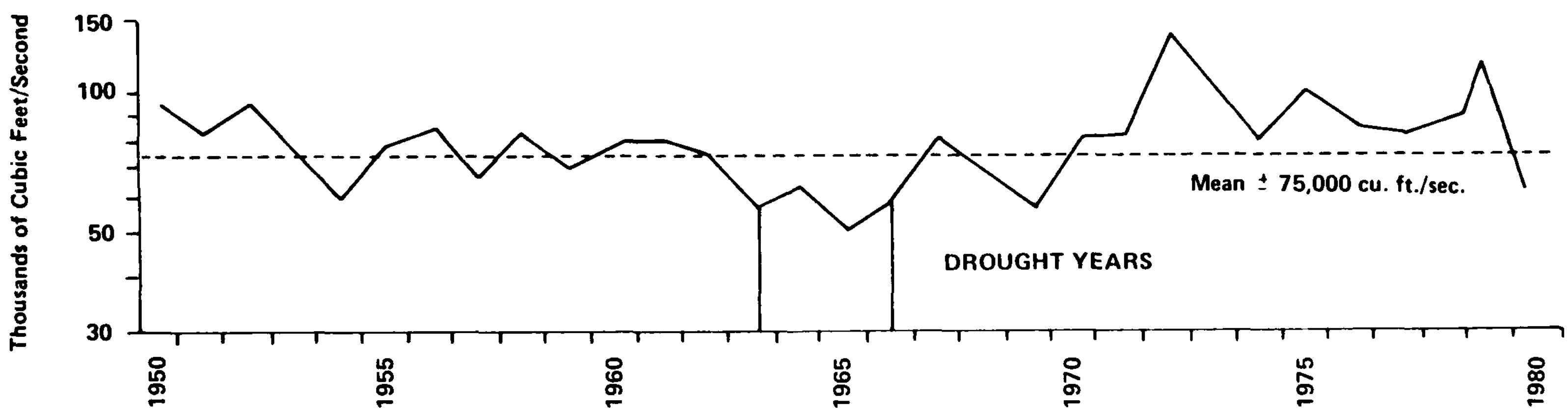

Figure 1. Average Streamflow into the Chesapeake Bay by Calendar Year.

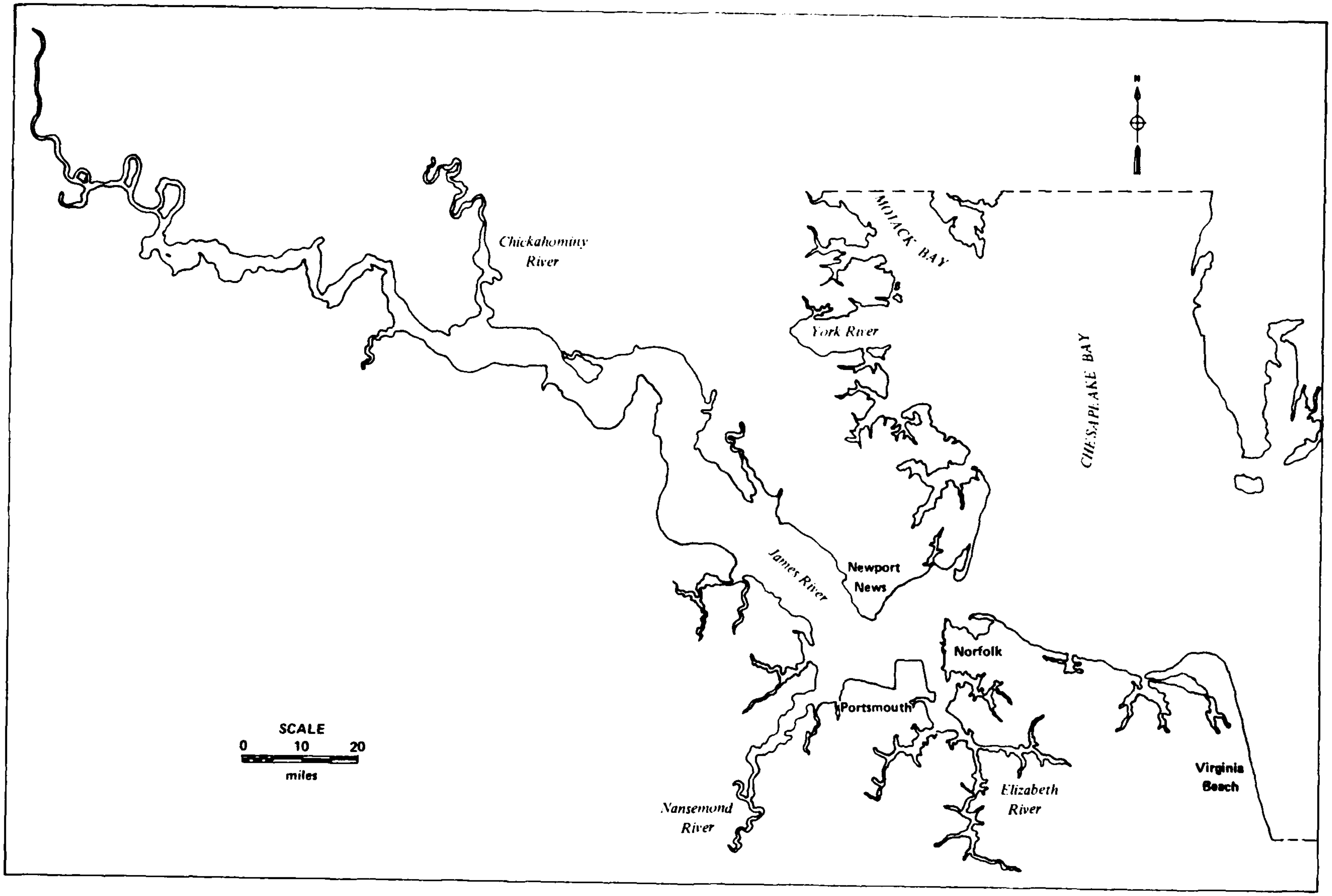

Figure 2. Study Boundaries for the Map Overlay Statistical System Analysis.

salinity data from the model has been stored in ASCII computer code and a printout of the entire data set is on file with the Corps and the Fish and Wildlife Service.

The salinity data provided by the Corps was converted from cumulative lunar days into calendar days to allow alignment with date and season. The source tape data was screened and obvious data errors were eliminated. Seasonal averages of the salinity data were then calculated for input into the Map Overlay Statistical System. Seasonal averages were selected because it is believed that long-term changes in a species' distribution would be attributed mainly to overall changes in seasonal salinities. Most estuarine organisms can adapt to relatively large salinity fluctuations for a short period of time. Any changes in habitat suitability would therefore be a result of the subtle changes in salinity that would occur over a long time frame. The seasons defined for salinity averaging were based on the "hydrographic" seasons and not calendar seasons, since many organisms (as well as salinity) are influenced by annual changes in flow. The four hydrographic seasons used for averaging the salinity data were:

Winter: December 1 to February 28

Spring: March 1 to May 31

Summer: June 1 to August 31

Fall: September 1 to November 30

The seasonal salinity averages for each of the stations within the study area under base and plan conditions are included in Appendix B.

Depth - Bathymetric data for the study area were obtained in digitized format from the National Geophysical and Solar-terrestrial Data Center of the National Oceanic and Atmospheric Administration. This data comes from surveys conducted by the National Ocean Survey (NOS) for the preparation of nautical charts and are based on a mean low water datum. The data were taken from surveys conducted prior to 1965; however it is believed that, with the exception of the channels, existing depths within the Chesapeake Bay will not differ significantly from the NOS survey. Depths for the channels within the study area were digitized separately utilizing the Corps' base and plan project channel dimensions plus an additional 3-feet for overdredging.

Substrate - The designation of sediment types within the study area was based on the classification system used in the LFIS, which includes the following categories:

	Sand Content
Sand	>75%
Muddy Sand	50-75%
Sandy Mud	25-50%
Mud	<25%

Information on sediment types was obtained from the following sources: Nichols, 1972a; Hawthorne, 1980; Nichols, 1981; Byrne, Hobbs and Carron, 1982; and Schaffner and Diaz, 1982. Map 2 of the map portfolio shows the sediment types within the study area.

Mapping Procedures

Species distribution maps were generated using a Geographic Information System (GIS) located at the Service's National Coastal Ecosystems Team in Slidell, Louisiana. The system has been developed to allow the Service to analyze habitat changes in applications that require extensive data analysis for large geographic areas. The GIS is a composite of three software packages developed and maintained by the Service's Western Energy and Land Use Team in Fort Collins, Colorado. These software systems and the hardware systems utilized are described below.

Wetlands Analytical Mapping System (WAMS) - WAMS performs data entry, verification, editing and initial storage procedures. Data can be entered in either point, line or polygon format from maps of differing scales. The hardware used with this system includes Altec digitizing tablets, Techtronics Graphic and Data General Dasher Terminals, and a Data General Eclipse S250 main frame computer.

Map Overlay Statistical System (MOSS) - MOSS performs the data base management and analysis functions and some cartographic display capabilities. In the present study MOSS was used to generate the habitat maps for each of the species and to determine the changes in distribution under base and plan conditions. The hardware utilized with this system was the Data General Eclipse S250.

Cartographic Output System (COS) - COS generates cartographically sound, hard copy plots of the maps produced by MOSS. A Calcomp 1050 drum plotter was utilized.

As described under "Data Sources", information for this study was input into the system from a variety of sources. The shoreline for the study area was digitized from the U.S. Geological Survey 7-1/2 minute topographic quadrangle maps at a scale of 1:24,000. Some of the small tributaries within the study area and the York River above the U.S. Route 17 bridge were not digitized because no salinity changes were expected in these areas. Sediment type information was first hand drawn onto the base map and then digitized. Information on the State owned oyster grounds was digitized from 1:10,000 maps provided by the Virginia Institute of Marine Science. The salinity data from the Corps and the bathymetric data from NOAA was entered into WAMS as point data and converted to cell format via an interpolation and gridding process. A cell size of 10 acres was selected as being appropriate for the density of the input data, while providing an acceptable habitat unit for impact evaluation.

Maps for each of the 20 study species were generated and are provided in the map portfolio that accompanies this report. These maps show each species' existing distribution, potential changes in distribution after the deepening project, and habitat acreage figures.

Limitations of the Study

Determining the accuracy of the predictions resulting from this analysis is of great importance, and at the same time, the most difficult aspect of this type of study. Each of the data sets used in the analysis and the methodology itself had limitations, which has a bearing on how closely the results will indicate the conditions that will actually occur in the Bay. These limitations are discussed in the following sections.

Salinity Data - The salinity data used in the Corps' hydraulic model test was based on an actual hydrograph from the years 1963 to 1965. The hydraulic model has been verified from salinity data collected by research institutions around the Chesapeake Bay. Prototype salinities have an accuracy between ± 0.2 ppt to ± 0.5 ppt and the hydraulic model salinities have an accuracy of ± 0.5 ppt.

The most significant limitation of this study is that the salinity data is based on a drought condition hydrograph. The salinities under this scenario differ significantly from the average or normal salinities that exist in the Chesapeake Bay. Figures 3a and 3b show how the base (drought) condition salinities utilized in this study compare to the long-term average salinities of the James River. It can be seen that the seasonal salinities for spring, summer and fall extend much further up river under the base condition than the long-term average. (However, it should be noted that there are some differences in the "seasons" on which these two data sets are based.) While the winter salinities under the base condition are higher than the long-term average in the downstream segment of the James, the upstream segment is fresher than the long-term average. This is explained by the fact that although the overall 2.5-year hydrograph represents a drought condition in the Bay, the winter freshwater inflows in the James River during that period were somewhat higher than normal.

Because drought conditions of the magnitude used in this study occur in the Bay sporadically, possibly at 20- to 30-year intervals (Mackiernan, et al., 1982), they do not represent the salinities to which organisms within the Bay are normally exposed. This fact affects this study in two ways. First, the

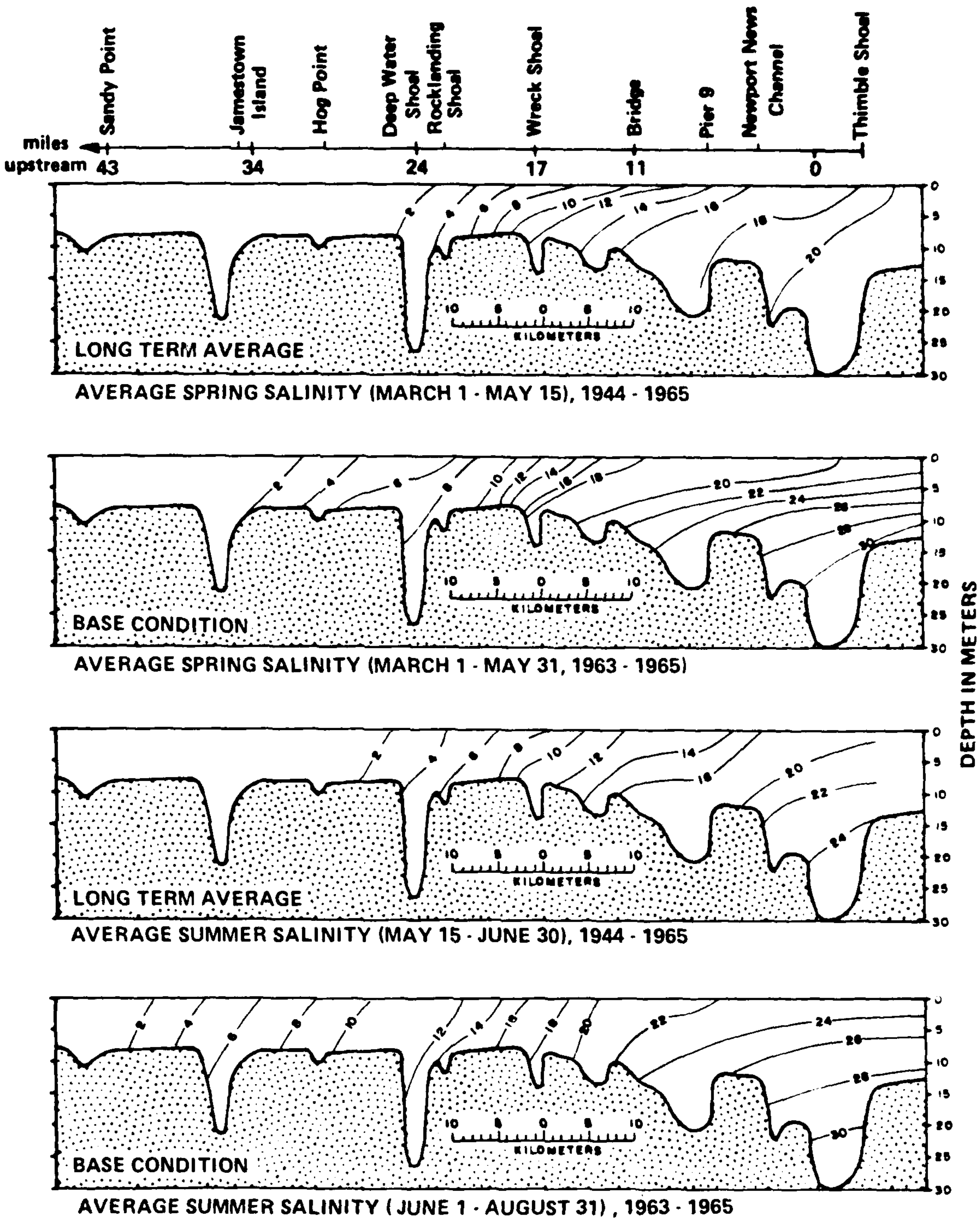

Figure 3a. Comparison of Long-Term Average and Model Hydrograph Isohalines for the James River.

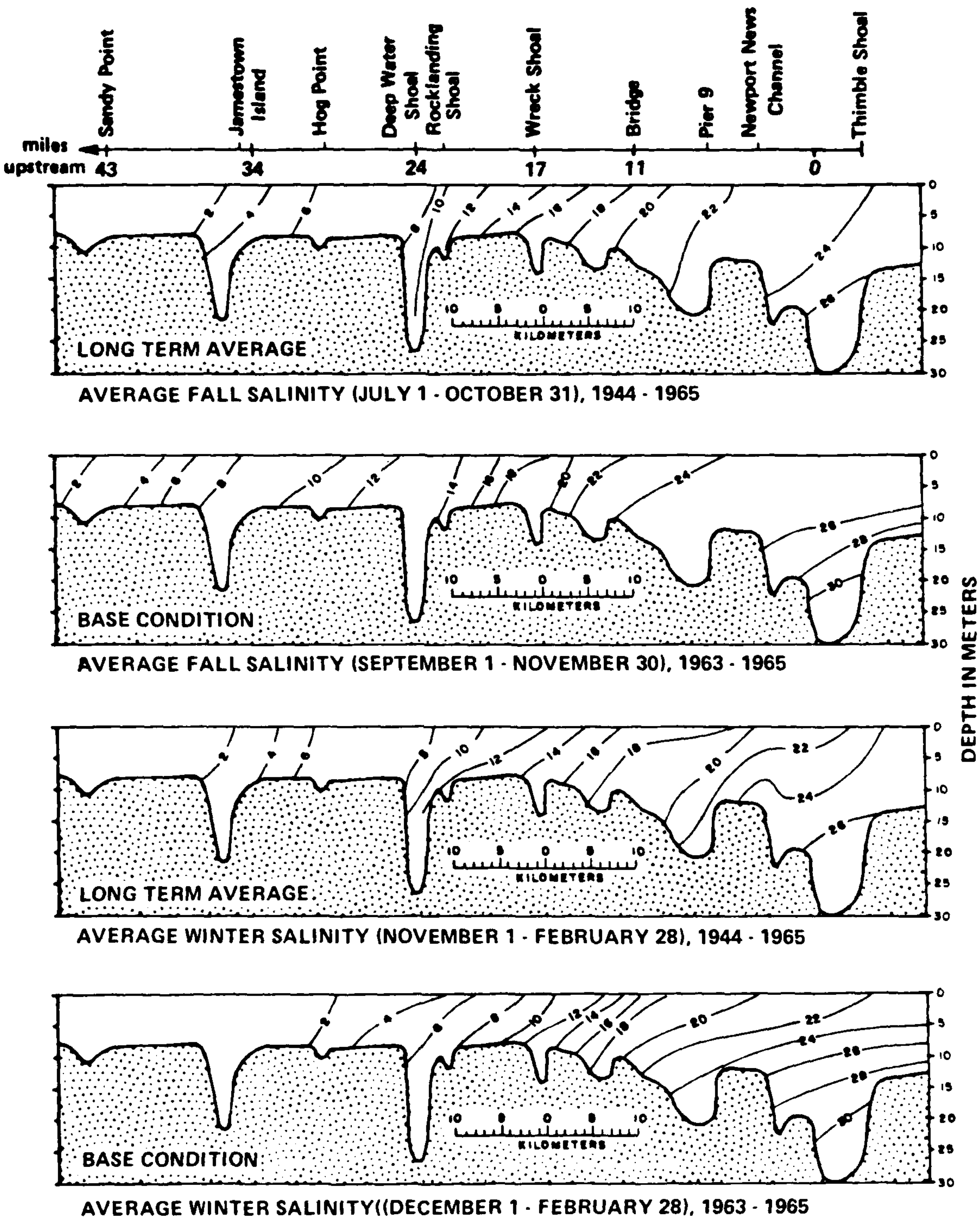

Figure 3b. Comparison of Long-Term Average and Model Hydrograph Isohalines for the James River.

habitat range maps do not necessarily reflect a species' normal distribution. For example, the map for the oyster drill, Urosalpinx cinera, indicates that this species' range extends up the James River to Burwell Bay. In reality, this benthic dweller is not found further upriver than the James River Bridge because normal spring freshwater flows limit its distribution. Therefore, the range maps may not accurately reflect a species' natural distribution, but rather its distribution under low flow conditions. Second, because the salinity data may not result in an accurate portrayal of a species' normal distribution, the prediction of habitat changes attributed to the channel deepening project is limited. While it is generally believed that this analysis provides a "worst case" estimate of habitat changes, an accurate prediction of habitat changes under normal salinity conditions is not entirely possible. In a previous model study to predict salinity changes associated with deepening the James River from 25 to 35 feet, Nichols (1972b) found that salinity changes in the James River would actually be greater under normal freshwater inflow conditions than under drought conditions.

Species' Habitat Criteria - The information on each species' habitat requirements for salinity, depth and substrate is based on field and laboratory studies and on the personal knowledge of Bay scientists. The accuracy of this information is considered high, however it does present a limitation to this analysis. Most estuarine species, with the exception of some oligohaline species, can tolerate a relatively wide range of salinities, which is an adaptation to the normal fluctuations that occur. Therefore, establishing a salinity range criteria of 8 to 26 ppt for the larvae of the bay anchovy (Anchoa mitchilli), for example, is somewhat arbitrary because this species would quite probably be found at salinities of 7 to 27 ppt. Therefore, changes in the salinity data set of 0.5 ppt or even 0.01 ppt will show up as a change in habitat distribution on the maps, whereas an actual change in distribution in the Bay probably will not occur.

Map Overlay Statistical System - Several features of the MOSS system presented some limitations to the analysis. As previously discussed, MOSS did not allow for 3-dimensional interpolation of the salinity data and therefore salinities could only be mapped at the surface and bottom. This limitation is not considered significant since an analysis of the surface habitat changes for organisms that are found throughout the water column should predict with relative accuracy overall habitat changes.

MOSS used an interpolation process to establish salinity and depth values for the entire study area on a 10-acre grid pattern based on the point data that was input into the system. This interpolation process affected the accuracy of the analysis in two respects. First, a 10-acre cell that happened to overlap a shallow area and a deep channel could have been assigned a depth value either higher or lower than the average depth of the cell, depending on where the data point was. Over the entire study area such differences should tend to cancel each other, however at any one location a depth value may not be quite accurate. Furthermore, the depth values for the channels were digitized separately using the Corps' authorized project dimensions. It should be realized that certain sections of these channels may be deeper than the project dimensions and that the maps could show potential habitat in cases where the depths are actually deeper than a species' range. Second, with respect to the salinity data, the interpolation process may result in the overestimation of habitat changes.

In summary, the analysis conducted to evaluate habitat impacts from the deepening project does have certain limitations that make accurate acreage predictions impossible. However, it is believed that the data and analysis methodology provides a valid general evaluation of the trends and magnitude of changes that would be expected.

RESULTS AND DISCUSSION

Distribution of Estuarine Organisms

The Chesapeake Bay generally has the typical estuarine two-layered circulation pattern in which fresher water occurs in the surface layers with a net movement down-estuary and more saline water occurs in the bottom layers with a net movement up-estuary. This two-layered system means that at any one point in the Bay, the surface salinities will generally be lower than bottom salinities. However, this two-layered system is influenced by the amount of freshwater inflow such that surface-to-bottom salinity variations are greatest during periods of high freshwater inflows (winter through spring) and least during periods of low freshwater inflow (summer through fall). In addition to these seasonal salinity patterns, daily tidal oscillations, monthly neap-spring tidal variations, and the effects of winds can result in fairly large salinity changes at any one location. Such natural salinity fluctuations require that estuarine organisms must be tolerant of such changes.

The modified "Venice System" has been established as an international classification of salinity zones within estuaries. These zones are as follows:

Tidal Freshwater	0-0.5 ppt
Oligohaline	0.5-5 ppt
Mesohaline	5 - 18 ppt
Polyhaline	18 - 30 ppt
Euhaline	30 ppt and above

This classification system generally corresponds to the zones of organism distribution within an estuary, although the biotic boundaries are not sharply defined. Most estuarine species have a wide salinity tolerance and their distribution reflects the interactions of physical and chemical parameters with the organisms' physiology, and biotic factors such as competition and predation. Boesch (1971, 1977) classified five major biotic groups within the lower Chesapeake Bay based on salinity tolerances, origin and reproductive requirements. Although Boesch was describing benthic communities, this classification generally is applicable to planktonic and nektonic species as well. The groups are:

> Stenohaline Marine - Organisms that are characteristic of the euhaline zone but occasionally are found within the estuary to about 25 ppt. Example: the blue mussel, *Mytilus edulis*.
>
> Euryhaline Marine - Organisms that extend from the euhaline zone into the high mesohaline-low polyhaline zone. Some species depend on recruitment from the ocean while others can reproduce within the estuary. Example: the hard clam, *Mercenaria mercenaria*.
>
> Euryhaline Opportunists - Organisms that are found from the euhaline to the oligohaline zone, but are most often found in greatest abundance in the low polyhaline and mesohaline zones. They can rapidly colonize disturbed or stressed habitats and salinity zones where less eurytopic (tolerant of wide salinity ranges) species are at a competitive disadvantage. Example: the polychaete worm, *Heteromastus filiformis*.
>
> Estuarine Endemics - Species that are limited to the estuary due to physiological tolerances, habitat requirements or competition. They are generally dominant below 15 ppt. Example: the Baltic macoma, *Macoma balthica*.
>
> Tidal Freshwater and Oligohaline - Species that are generally restricted to salinities below 0.1 ppt but may be found to 5 ppt or higher. This group includes a mixture of eurytopic freshwater species and estuarine endemics. Example: the copepod, *Scottolana canadensis*.

Based upon these five groups of estuarine organisms, it is possible to define the types of salinity-induced changes that could occur as a result of a channel deepening project. For species that are tidal freshwater or oligohaline, and some estuarine endemics, there could be an up-estuary shift in their downstream boundary resulting in a reduction in habitat. For stenohaline and euryhaline marine and opportunistic species there could be an up-estuary shift in their upstream boundary resulting in an increase in habitat. Finally, there could be a shift in both the upstream and downstream boundaries for euryhaline opportunists and estuarine endemics, with little overall change in habitat.

Results of the Physical Model Test

A full evaluation and discussion of the results of the physical model study may be found in Richards and Morton (1983). The following is a brief synopsis of the findings presented in the Corps' report.

Tidal Phasing - No change in tidal phasing is predicted. The accuracy of this test was ±18 degrees.

Water Levels - No change in water surface elevations is predicted. The accuracy of the computed mean water level was ±0.10 foot.

Tidal Amplitude - No changes in tidal amplitudes are predicted. The accuracy of the test was ±0.10 foot.

Velocity Phasing - The only phasing difference between the base and test plan occurred at station EH0501, which is at the confluence of the Southern and Eastern Branches of the Elizabeth River. At this station the plan phase consistently arrived earlier than the base phase. The accuracy of the phasing test is approximately ± 20 degrees.

Velocity Amplitude - The overall mean of the current speed differences indicated a 0.13 feet per second (fps) decrease in the plan. Changes were seen in the lower Bay stations, the James River stations up to ranges JN02 an JG03, and in the Elizabeth River. The accuracy of this test was ±0.03 fps.

Mean Velocities - Overall, there was no change in mean velocities for the entire data set. Over 97 percent of the base and plan velocities were within 0.40 fps of one another (with an accuracy of ±0.03 fps). The following stations showed a consistent increase in mean velocity:

CB0001	Depth of 4 feet
TS0003	Depths 4 and 46 feet

JG0103	Depths 22 and 66 feet
JN0204	Depth 48 feet
EH0701	Depth 4 feet

Stations showing a consistent decrease in mean velocity are:

CB0004	Depth 4 feet
TS0005	Depth 50 feet
EH0202	Depth 46 feet

Maximum Flood and Ebb Velocities - There was an overall decrease in maximum flood and ebb velocities of approximately 0.10-fps after channel deepening due to the increase in cross-sectional area associated with the deeper channels. Approximately 82 percent of the base to plan changes were within 0.4-fps.

Flow Predominance - During the high discharge test there was an overall increase in ebb predominance. There was a decrease in ebb predominance under the average discharge test. Flow predominance values are given in percent of flow in the ebb direction. The overall mean difference was 0.57 per cent, with approximately 97 percent of the values within 20 percent. These changes indicate possible changes in local shoaling patterns, which are further addressed in Berger et al. (in press).

Salinity - No changes in salinity distribution in the Chesapeake Bay were seen north of station range CB01, located east of the mouth of the Back River. The greatest differences occurred in the deepened channels where increases in bottom salinities varied between 0 and 4.0 ppt. Shallow-water areas near deepened channels showed a much smaller increase in salinities and at some shallow stations there was actually a slight decrease in salinities due to transverse redistribution of salt water in the cross section. A small dampening of the neap to spring range of bottom salinities (1 ppt) occurred in the Elizabeth River. Little if any neap-spring changes were detectable elsewhere. The accuracy of base to plan salinity differences from the model is ± 1 ppt.

Determination of Threshold of "Significant" Habitat Changes

The limitations on the accuracy of the data and methodology used in the evaluation of habitat changes were discussed under "Methods". These limitations, as well as the factors discussed below, were taken into consideration in determining whether the habitat changes predicted by the MOSS analysis would correspond to "actual" changes in the real world.

As previously mentioned, the accuracy of the base to plan salinity differences was estimated to be ± 1 ppt (Richards and Morton, 1983). However, the salinity data reported in the Corps' study and utilized in the MOSS analysis was carried out to two decimal places (0.00). Therefore, changes in average seasonal salinities of as little as 0.01 ppt could result in the prediction of a habitat change for a species. Since this type of analysis exceeds the accuracy of the data, it is very likely that habitat changes were overestimated. Furthermore, normal salinity variations of up to 5 to 8 ppt can occur at any one location within the lower Bay due to daily and monthly tidal cycles and annual freshwater inflow patterns (Richards and Morton, 1983). Since estuarine organisms have adapted to these relatively frequent salinity changes, small long-term salinity changes may have little effect on their distribution. Other variables may be as or more important than salinity in determining a species' range. Such factors can include competition, predators, dissolved oxygen and pollutants. These factors were not considered in the model evaluation.

In most scientific studies it is usual to undertake a statistical analysis of the confidence limits of the data. However, because much of the data used in this study were not based on statistical sampling (i.e. habitat requirements), an analysis of confidence limits is not appropriate. Therefore, a judgement was made that assumed that habitat changes of less than 5% may fall within the limit of error of this study and that such changes should not result in any significant impacts to a species' distribution or population levels.

Results of MOSS Evaluation of Habitat Changes

Table 4 presents the results of the Map Overlay Statistical System (MOSS) evaluation of potential habitat changes for each of the twenty species. Because of the limitations discussed previously, the acreage figures presented in Table 4 should not be analyzed separately from the following discussion of each species.

Chrysaora quinquechirra (sea nettle) - The maps for this species show the distribution of the polyp stage shifted further upstream than its distribution during years of normal freshwater inflow. Likewise, the range for the medusa stage is also indicated as further upstream than normal. Under plan conditions, MOSS predicted virtually no change in habitat for the medusa stage (+0.1%) and a small decrease (-2.8%) in habitat for the polyp stage. The decrease in habitat for the polyp stage would be less than indicated on the map. The approximately 290 acre loss shown in the Western Branch of the Elizabeth River is due to a computer error. The map also indicates a habitat loss in the middle section of the Nansemond River. However, under normal salinity conditions this habitat loss would be smaller. Overall impact: The sea nettle may undergo a slight upstream shift in available habitat for the polyp stage and no change in the medusa's range. The predicted habitat change

Table 4. Potential Habitat Changes Resulting from the Norfolk Harbor Deepening Project (Note: the reader is cautioned not to interpret these values without reading accompanying text.)

Species	Potential Habitat Base Condition (Acres)	Habitat Change Plan Condition		Per Cent Habitat Change
		Increase	Decrease	
Chrysaora quinquechirrha (sea nettle)				
Medusa	628,640	740	0	+ 0.1%
Polyp	47,180	3,480	4,820	- 2.8%
Acartia clausi (copepod)	604,610	1,310	0	+ 0.2%
Eurytemora affinis (copepod)	42,110	1,860	1,580	+ 0.7%
Scottolana canadensis (copepod)	17,570	690	2,550	-10.6%
Pectinaria gouldii (polychaete worm)	78,150	2,330	10,760	-10.8%
Scolecolepides viridis (polychaete worm)	59,310	1,450	3,720	- 3.8%
Urosalpinx cinerea (oyster drill)	389,880	4,350	1,630	+ 0.7%
Crassostrea virginica (oyster)	407,560	1,790	1,630	+ 0.04%

Table 4. (Cont'd.)

Species	Potential Habitat Base Condition (Acres)	Habitat Change Plan Condition Increase	Habitat Change Plan Condition Decrease	Per Cent Habitat Change
Mercenaria mercenaria (hard clam)	430,460	980	2,000	- 0.2%
Macoma balthica (Baltic macoma)	31,860	290	290	0%
Balanus improvisus (barnacle)	53,330	2,330	4,540	- 4.1%
Cyathura polita (isopod)	37,260	250	2,700	- 6.6%
Ampelisca abdita (amphipod)	92,160	1,790	240	+ 1.7%
Leptocheirus plumulosus (amphipod)	34,250	1,440	1,150	+ 0.8%
Palaemonetes pugio (grass shrimp)	29,800	1,310	2,440	- 3.8%
Callinectes sapidus (blue crab)				
Male and Juvenile Female	55,790	2,270	4,740	- 4.4%
Adult Female	391,520	1,710	1,410	+ 0.1%
Adult Female with Eggs	314,442	4,730	1,410	+ 1.0%

Table 4. (Cont'd.)

Species	Potential Habitat Base Condition (Acres)	Habitat Change Plan Condition		Per Cent Habitat Change
		Increase	Decrease	
Callinectes sapidus, cont'd.				
Zoea Larvae	229,730	18,690	540	+ 7.9%
Alosa sapidissima (American shad)	67,550	0	3,080	- 4.6%
Brevoortia tyrannus (menhaden)	68,970	1,480	0	+ 2.1%
Anchoa mitchilli (bay anchovy)	476,690	4,860	10,290	- 1.1%
Morone saxatilis (striped bass)	60,880	0	1,910	- 3.1%

is within the limit of error of the analysis.

Acartia clausi (copepod) - The map shows the range for this species extending further upstream than under normal salinity conditions. MOSS predicted a small (+0.2%) increase in habitat availability under low flow conditions. Overall impact: A small upstream increase in habitat is possible. The predicted habitat change is within the limit of error of the analysis.

Eurytemora affinis (copepod) - Although this species is mapped at its high spring population distribution, its range also extends into the oligohaline zone. MOSS predicted small habitat losses in the James, Nansemond, and Southern Branch of the Elizabeth Rivers and an approximately equal habitat gain upstream in the James River. The habitat changes indicated in the Western Branch of the Elizabeth River were due to computer error and should be discounted. Overall impact: No change in available habitat for this species is anticipated. The predicted change (+0.7%) is within the limit of error of the analysis.

Scottolana canadensis (copepod) - This species was mapped at the salinities at which it is found in greatest abundance (1 to 5 ppt); however it is also found in freshwater so the species' total range is greater than indicated. The map also shows the 1 to 5 ppt segment of the James River shifted upstream from normal conditions. MOSS predicted a small increase in upstream habitat offset by a larger loss of downstream habitat resuting in a decrease of approximately 11% in available habitat. Overall impact: If the salinity shifts that occur under low flow conditions also occur under normal conditions there could be a long-term loss of habitat for this species. This copepod is an important food source for juvenile sciaenid fish and other benthic feeders and a reduction in this species may cause secondary impacts to the food chain.

Pectinaria gouldii (polychaete worm) - The map for this species shows a shift in its range upstream from normal conditions. MOSS predicted small habitat increases in the Nansemond and James Rivers and the Chesapeake Bay and a habitat loss in the Elizabeth River. MOSS also predicted a large habitat loss (10,000 acres) in the Chesapeake Bay east of the York River. This loss is not expected to occur and points out the limitations of this type of analysis. The Corps' physical model test resulted in small salinity differences between base and plan conditions during the first spring of the hydrograph in the middle section of the Bay. These differences were due to probl in model stabilization and were not actual changes expected to result from the deepening project (Richards and Morton, 1983). These differences were seen in the MOSS evaluation as an increase in average spring salinity at Station YS0004 from 27.55 ppt to 28.24 ppt. Since 28 ppt was used as the upper salinity tolerance for Pectinaria, MOSS interpreted this change as a habitat loss. Overall impact: A small loss of potential habitat in the Elizabeth River will be offset by increases in the Nansemond and James Rivers and Chesapeake Bay. No significant changes are anticipated.

Scolecolepides viridis (polychaete worm) - MOSS predicted a small gain in upstream habitat in the James River offset by slightly larger losses of downstream habitat in the James River, with an overall loss of approximately 3%. The habitat loss shown in the Western Branch of the Elizabeth River is due to computer error and should be discounted. Overall impact: A small upstream shift in habitat is possible. The predicted habitat change is within the limit of error of the analysis.

Urosalpinx cinera (oyster drill) - The map for this species shows its range extending much further upstream in the James River than it normally occurs. The drill's normal distribution does not extend above the James River bridge. MOSS predicted a small (1600-acre) habitat loss in the navigation channels as depths increase beyond its range limit. However, the channels are presently outside the drill's normal distribution because there is no hard substrate or food source within the channels. MOSS also predicted a 4300 acre increase in potential habitat in the James River. The normal distribution of this species in the James River is limited by spring freshets which reduce salinities and prevent upstream migration. Since these spring freshets should not be affected by the deepening project no habitat increases are anticipated. Overall impact: No habitat changes for this species under normal or low flow conditions are anticipated.

Crassostrea virginica (oyster) - The map for this species shows its range extending further up the James River than it normally occurs. Its normal range extends to approximately Deep Water Shoals. MOSS predicted a small (1600-acre) loss of habitat in the channels as these areas are deepened below the oyster's depth range. However, the channels do not currently serve as habitat for the oyster as there is no suitable substrate for attachment. MOSS also predicted a small (1800 acre) increase in upstream habitat. The oyster's actual downstream distribution depends on the presence of its major predator, the oyster drill and the disease organisms MSX (Haplosporidium nelsoni) and "dermo" (Perkinsus marinus), which are found in salinities of about 15 ppt and greater. As with the oyster drill, both MSX and dermo are limited in upstream distribution by spring freshets and not seasonal average salinities. Overall impact: There may be a small increase in potential upstream habitat for the oyster if suitable subtrate for attachment is present. The predicted habitat change is within the limit of error of this analysis.

Mercenaria mercenaria (hard clam) - This species is mapped at approximately its normal range. MOSS predicted a small (960-acre) increase in upstream availability and a 2000-acre loss of habitat in the navigation channels as a result of dredging. However, some sections of the navigation channels are already deeper than the hard clam's normal depth. Clams are not found in high abundance in any of the channels due to a lack of suitable substrate. Overall impact: A small increase in upstream habitat is possible but no significant change is anticipated.

Macoma balthica (Baltic macoma) - The map shows the range of this species shifted upstream of its normal distribution. MOSS predicted a small (290-acre) loss of downstream habitat offset by an equal gain in upstream habitat. Overall impact: No change in available habitat for this species is anticipated.

Balanus improvisus (barnacle) - The map shows this species' range shifted upstream from its normal distribution. The barnacle is not normally found upstream of Deep Water Shoals. MOSS predicted a loss of habitat in the

Nansemond River as salinity increases in the middle section of the river. A loss of downstream habitat in the James River is offset by an increase in habitat upstream. The habitat loss shown in the Western Branch of the Elizabeth River was due to computer error and should be discounted. Overall impact: A small usptream shift in available habitat is possible but no significant change is expected for this species.

Cyathura polita (isopod) - The map for this species shows its range shifted upstream from its normal distribution. MOSS predicted a small (250-acre) gain in upstream habitat and a larger (2700-acre) decrease in downstream habitat, resulting in an overall habitat loss of 6.8%. Overall impact: A loss of downstream habitat for this species is possible. This species is a food source for benthic-feeding finfish so a decrease in habitat availability could have secondary impacts on other levels of the food chain.

Ampelisca abdita (amphipod) - This species is mapped at close to its normal range. MOSS predicted a small (240-acre) habitat loss and an approximately equal habitat gain at the mouth of the Chesapeake Bay and an 1800-acre habitat gain in the James and Elizabeth Rivers, for an overall habitat increase of 1.7%. Overall impact: No significant change in habitat is anticipated for this species.

Leptocheirus plumulosus (amphipod) - The map shows this species' range shifted upstream from its normal distribution. MOSS predicted a loss of downstream habitat offset by a nearly equal increase in upstream habitat, resulting in an overall habitat increase of 0.8%. Overall impact: A small upstream shift in habitat is possible but no significant habitat changes are anticipated for this species.

Palaemonetes pugio (grass shrimp) - The map for this species shows its range shifted upstream from its normal distribution, which includes most of the Hampton Roads area. MOSS predicted a small loss in downstream habitat in the James River which is offset by an approximately equal increase in upstream habitat. A loss in habitat in the Nansemond River is also indicated. The habitat loss shown in the Western Branch of the Elizabeth River is due to computer error and should be discounted. Overall impact: An upstream shift in habitat is possible with an overall decrease of less than 3%. No significant change in available habitat is anticipated.

Callinectes sapidus (blue crab) - The blue crab has a wide salinity tolerance and is found virtually throughout the Chesapeake Bay. However, the species shows definite salinity preferences based on sex, life stage and time of year. Because of these differences and the blue crab's importance as a fishery resource, four separate maps were generated for this species. All of the maps show the range of the blue crab shifted upstream from its normal high density summer distribution.

Males and Juvenile Females - MOSS predicted a loss of downstream habitat in the James River offset by a nearly equal increase in upstream habitat. The loss of habitat predicted in the Nansemond River is greater than what would actually occur since these two groups will probably continue to use the habitat even if the salinities increase slightly. The habitat loss indicated in the Western Branch of the Elizabeth River is due to a computer error and should be discounted.

Adult Females - MOSS predicted a habitat increase (1700-acres) in upstream habitat in the James River and a loss (1400-acres) of habitat in the channels after dredging. However, the existing channels do not currently provide optimal summer habitat for this species, so this is not expected to be an actual habitat loss.

Adult Females with Eggs - MOSS predicted an approximately 4700-acre habitat gain in upstream habitat in the James and Nansemond Rivers. The predicted habitat loss within the channels, as previously explained, is not an actual loss.

Zoea Larvae - MOSS predicted a large (18,700-acre) increase in available habitat in Hampton Roads and the Chesapeake Bay, resulting in an overall increase of approximately 8%. However, under normal freshwater inflow conditions the spawning and nursery area does not extend into Hampton Roads. Therefore, although an increase in habitat is possible, the extent should not be as large as predicted. The small (540-acre) habitat loss in the Chesapeake Bay is a result of the MOSS interpolation process and is not considered to indicate a true habitat change.

Overall impact: Although a small increase in zoea larval habitat is possible, no significant changes in available habitat for this species is anticipated.

Alosa sapidissima (American shad) - The map shows the range for juvenile shad upstream of this life stage's normal summer distribution. MOSS predicted a 3000-acre loss in downstream habitat for this species, resulting in a 4.6% decrease in overall habitat. However, this life stage would be affected more by changes in food sources and predators than by changes in salinity. Although this species is of particular concern because of its reduced population levels within the Chesapeake Bay, it would be difficult to predict a significant impact to this species because of the limitations of the analysis methodology. Overall impact: A small loss of juvenile habitat is possible but no significant impacts on overall population levels are anticipated.

Brevoortia tyrannus (menhaden) - The menhaden is an ocean spawner whose postlarvae and juveniles utilize the upper estuary as a nursery zone. Therefore, although the young are found throughout the Bay, they predominate in the oligohaline zone where their preferred food sources are found. The map shows this species' range extending further downstream in the James River than under average winter conditions. It also shows the upstream range extending to Richmond; however they are not normally found in high densities much farther upstream than the Chickahominy River. MOSS predicted a 1500-acre increase in downstream juvenile habitat resulting in an overall increase of approximately 2%. Overall impact: A small increase in available habitat is possible but no significant change in juvenile distribution is anticipated.

Anchoa mitchilli (bay anchovy) - The map shows the range of eggs and larvae for this species shifted upstream from their normal distribution. MOSS predicted a 10,000-acre loss in downstream habitat at the mouth of the Chesapeake Bay and a 5000-acre increase in habitat in the James River, resulting in an overall habitat loss of approximately 1%. Overall impact: A small shift in available habitat for early life stages is possible but no significant changes in overall habitat is anticipated.

Morone saxatilis (striped bass) - The map shows the range for juvenile striped bass shifted upstream of this life stage's normal summer distribution. MOSS predicted a 1900-acre loss of downstream habitat, resulting in an approximately 3% decrease in overall habitat. Like the American shad, juvenile striped bass are more affected by food sources and predator distribution than salinity levels. The striped bass is also a species of particular concern because of its extremely low population levels in the Chesapeake Bay. The limitations of the analysis methodology indicate that the predicted habitat loss is within the limit of error. Overall impact: A small loss of juvenile habitat is possible, but no significant impacts on overall population levels are anticipated.

Ecosystem Implications

The primary purpose of evaluating habitat changes associated with individual species is to predict overall ecosystem impacts. Each of the twenty species utilized for this analysis is part of a complex system involving numerous physical, chemical and biological interactions. The reader is referred to the Low Freshwater Inflow Study (Mackiernan et al., 1982) for a detailed discussion of the ecological relationships that are present in the Chesapeake Bay.

Although the numerical values for habitat changes predicted by MOSS cannot be taken as totally accurate due to the limitations of the methodology, general trends are evident. Table 5 presents the three categories of habitat changes that will occur as a result of the deepening project. The first category includes organisms which will undergo no overall change in available habitat due to equal shifts in upstream and downstream range limits. Ten organisms or life stages fell into this category, most of which are mesohaline to euhaline zone inhabitants or are euryhaline. The second category includes species that will undergo an increase in available habitat due to an overall increase in their upstream range. Four organisms or life stages fell within this category, all of which are inhabitants of the poly- to euhaline zones. With the exception of the blue crab zoea larvae, all of the increases were extremely small.

Table 5. Categories of Potential Habitat Changes

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1. Shift in both upstream and downstream boundaries (Less than 1% overall habitat change):

   Chrysaora quinquechirrha - sea nettle (medusa)
   Acartia clausi - copepod
   Eurytemora affinis - copepod
   Pectinaria gouldii - polychaete worm
   Urosalpinx cinerea - oyster drill
   Mercenaria mercenaria - hard clam
   Macoma balthica - Baltic macoma
   Leptocheirus plumulosus - amphipod
   Callinectes sapidus - blue crab (adult females)

2. Shift in upstream boundaries (increase in total habitat):

   Ampelisca abdita - amphipod
   Callinectes sapidus - blue crab (adult females with eggs and zoea larvae)
   Brevoortia tyrannus - menhaden (postlarvae and juveniles

3. Shift in downstream boundaries (reduction in total habitat):

   Chrysaora quinquechirrha - sea nettle (polyp)
   Scottolana canadensis - copepod
   Scolecolepides viridis - polychaete worm
   Balanus improvisus - barnacle
   Cyathura polita - isopod
   Palaemonetes pugio - grass shrimp
   Callinectes sapidus - blue crab (adult males and juvenile females)
   Alosa sapidissima - American shad (juveniles)
   Anchoa mitchilli - Bay anchovy (eggs and larvae)
   Morone saxitilis - striped bass (juveniles)

The third category includes species that will undergo a reduction in available habitat due to an overall loss in downstream range. Ten species or life stages fell within this category, which primrily are inhabitants of the oligo- to mesohaline zones. This category includes the largest percentage changes in available habitat. Two oligo- to mesohaline species, the copepod Scottolana canadensis and the isopod Cyathura polita showed the largest habitat changes of any of the species (approximately 11% and 7% respectively). This raises some concern because both of these species are important food organisms for juvenile fish in the nursery zones. The actual effect that such changes could have on finfish populations may depend on the ability of these fish to change food sources. However, so little is known about the factors that influence juvenile finfish mortality and survival that it is difficult to say with confidence that there would be any significant ecosystem changes caused by salinity shifts in the oligo- to mesohaline zone.

The overall habitat changes predicted by MOSS follow the expected patterns when salinities within an estuary are increased. That is, there will be small upstream shifts or increases in habitat for meso- to polyhaline species, and somewhat larger decreases in habitat for oligo- to mesohaline species. These changes will occur mainly in the James and Nansemond Rivers. The level of change, which in no case exceeded 11%, is small enough that any ecosystem changes would be extremely subtle, and in fact could probably not be demonsrated through field sampling. It is anticipated that if such shifts in habitat do occur, the inherent adaptability of the estuarine species found in the lower Bay will result in no significant adverse effects to the ecosystem.

CONCLUSIONS

The results of the physical model test indicate that there will be no changes in tides or currents in the lower Chesapeake Bay and James River basin that would be large enough to cause any impacts to aquatic resources. Changes in salinities will result in subtle shifts in habitat, primarily in the oligo- to mesohaline section of the James River. These shifts are quite small and there should be no discernable ecosystem changes. However, the results of this study, when looked at in conjunction with the results of the Low Freshwater Inflow Study, do indicate that significant long-term cumulative impacts to the Bay could result if consumptive water uses reduce the flow of freshwater into the estuary. While the Bay ecosystem can adapt to the small changes in salinities caused by major channel deepening projects, the cumulative effects of these projects and future water withdrawals could lead to significant ecosystem changes. It is therefore imperative that resource managers at both the state and federal levels conduct detailed impact evaluations of the effects of proposed alterations of freshwater inflow to the Chesapeake Bay.

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APPENDIX A

DESCRIPTION OF STUDY SPECIES

Description of Study Species

The following description of the twenty species utilized in the Map Overlay Statistical System evaluation is taken from the Chesapeake Bay Low Freshwater Inflow Study Biota Assessment (Shea, et al., 1980). In most cases, the habitat criteria utilized in the Map Overlay Statistical System evaluation is the same as that used in the LFIS. However, for some species the habitat criteria from the LFIS were modified to correspond to known habitat ranges in the James River and lower Chesapeake Bay.

Chrysaora quinquecirrha - Sea nettle (Maps 3 and 4)

Description - The sea nettle is a moderately large jellyfish of the family Pelagiidae. Like all of this group it exhibits alternation of generations between the pelagic medusa form (the familiar sea nettle) and the small sessile epibenthic polyp. The medusa ranges up to 200 mm in bell diameter, with 24 to 72 trailing tentacles well-armed with nematocysts, and four frilled trailing oral lobes. The usual color is white, but pink or red individuals occur, particularly in the lower Bay. The cryptic polyp is only about 4-mm high, with 16 to 20 tentacles, found attached to hard substrates.

Range - Chrysaora quinquecirrha is found in warm temperate areas world-wide. It apparently reaches its maximum abundance in estuaries such as the Chesapeake Bay. In the Chesapeake it occupies differing areas depending on life stage and season. The medusa is found during the warmer months (particularly July and August) in mesohaline and polyhaline areas. It reaches highest numbers in the mesohaline tributaries, rather than the Bay mainstem. Despite the economic effect of this species in restricting recreation, good biomass and abundance data is lacking for virtually every area of the Bay. The year-to-year abundance seems extremely variable.

Eggs and sperm released by the medusae produce ciliated planula larvae, which settle on appropriate hard surfaces and give rise to the sessile polyp stage. Polyps form resting cysts in cold months, or when conditions are unfavorable. One polyp may form numerous cysts. Through asexual reproduction the polyps produce ephyrae, which are released in early summer when water temperatures reach 20°C. These ephyrae grow and mature into medusae, completing the cycle. Medusae first appear in numbers in Bay tributaries, eventually occurring in the mainstem.

Salinity Relationships - The medusae are rarely found at salinities below 5 ppt and extend into nearshore marine waters (34 ppt). Polyps have a more restricted salinity range, and occur generally between 7-20 ppt where suitable habitat exists.

Freshets which reduce salinities over a relatively long time span can kill the polyps, thus reducing later medusa abundance, as in 1972 after Tropical Storm Agnes.

Other Sensitivities - The medusae are limited by temperature, and are generally found above 20°C. Polyps are also limited by their need for hard substrates, and are thus additionally affected by sedimentation. Anoxic or hypoxic conditions in summer in deep water, as well as preponderance of soft substrate, tends to limit polyps to less than 10-m depth. However, they can occur more deeply in areas of high dissolved oxygen and good circulation.

Trophic Importance - Both polyps and medusae feed upon zooplankton, with the powerfully armed medusae also able to capture small fish, worms, and crustaceans. When abundant, Chrysaora medusa can probably exert significant grazing pressure on zooplankton populations. Clifford and Cargo (1978), estimate that a moderate sized medusa can consume approximately 18,800 copepods per day in summer. Chrysaora medusae also feed upon the ctenophore

Mnemiposis, reducing its numbers.

Few organisms eat the *Chrysaora* medusae, but among them are the butterfish, *Peprilis triacanthus*, and the harvestfish *P. alepidotus*. These fish also have a commensal relationship with *Crysaora*, as the juvenile fish shelter within the medusa's tentacles (Mansueti, 1963).

The polyp is preyed upon by various species which feed upon hydroids, particularly nudibranchs such as *Cratena* sp. Barnacles and other planktivores have been shown to capture and ingest the ephryae (Cones and Haven, 1969).

Selection Factors -

- Economic importance of the medusae in restricting recreational use of Bay waters in summer.
- Potential of extension of range upstream in Bay and tributaries due to increased salinities.
- Trophic importance of species as a predator of zooplankton and small fish.

Sources -

Burrell, 1972
Cargo and Schultz, 1966; 1967
Clifford and Cargo, 1978
Cones and Haven, 1969
Lippson, 1973
Lippson *et al.*, 1979
Gatz *et al.*, 1973
Littleford, 1937
Loeb, 1972
Mansueti, 1963
Mihursky and Boynton, 1978
Miller, 1970; 1974
Schultz and Cargo, 1971*

* Reference was not given in the Low Freshwater Inflow Study.

Acartia clausi - Copepod (Map 5)

Description - Acartia clausi is a small (1-mm) calanoid copepod of the family Acartiidae. It is extremely abundant seasonally in the Chesapeake Bay.

Range - A. clausi is an estuarine and neritic species of cool temperate and boreal affinities, typically most abundant in near-shore areas. In Chesapeake Bay, the species occurs only during the winter and early spring months when water temperatures are suitable for its reproduction. It is generally more important numerically, and more persistent in the higher salinity areas of the estuary. In Chesapeake Bay it is a winter-spring codominant with its congeneric A. tonsa. In mesohaline regions, A. clausi first appears in late November or December, reaches a maximum abundance (5-10,000 individuals per m^3) in March, and is gone from the plankton by May. In the polyhaline lower Bay, the species can reach densities of over 20,000 organisms per m^3 and constitute over 99% of the total zooplankton in March and April. It generally persists until June in these areas.

Salinity Relationships - A. clausi is not as tolerant of reduced salinities as is A. tonsa and reaches its maximum abundance in the Bay at salinities greater than 10 ppt. However, it can be found down to 3 ppt in the upper Bay and tributaries. Above 18 ppt it is sometimes reduced in numbers by influx of neretic carniverous zooplankton from the shelf (Grant and Olney, 1979), although polyhaline salinities do not limit its distribution. The habitat range used for this species is 5 to 34 ppt.

Sensitivity and Potential Habitat - A. clausi is limited by temperature in Chesapeake Bay. In general, temperatures above 20°C are not favorable for reproduction and survival. Between 11° and 18°C, A. clausi appears to be at a competitive disadvantage in relation to A. tonsa in lower salinity water. For this reason, the observed succession of tonsa over clausi in spring occurs first in the upper Bay and tributaries and proceeds down bay. A. clausi filters more efficiently and respires less than A. tonsa at low temperatures (Anraku, 1964). It can reproduce at temperatures as low as 4°C.

Trophic Importance - A. clausi is a selective filter feeder on phytoplankton and detritus and also exhibits a certain amount of selective raptorial feeding on small zooplankton (including nauplii of various copepods). It can adjust its feeding strategy to take advantage of the most numerous size class of phytoplankton available, and can "track" the various biomass peaks so as to maximize feeding efficiency. There is also a tendency to select for the larger particles. When abundant, A. clausi can exert a significant grazing pressure on the phytoplankton populations.

The two Acartia spp. are important contributors to the estuarine food web. Although A. clausi is not found in the major fish nursery areas, it nevertheless is used as food by juvenile fish, and carniverous zooplankton such as jellyfish and ctenophores. A. clausi also acts as a source of regenerated nutrients (primarily nitrogen and phosphorus), as do other zooplankton.

Selection Factors -

- Trophic importance, both as a grazer and as a source of food for other organisms.

- Potential expansion of range due to increased salinity.

Sources

Acad. Nat. Sci. Phila, 1977; 1978
Anraku, 1964*
Burrell, 1972
Goodwyn, 1970
Grant and Olney, 1979
Heinle, 1966; 1979
Herman et al., 1968
Jacobs, 1978
Knatz, 1978
Richman et al., 1977
Rupp, 1969
Sage and Olson, 1977
Storms, 1975

* Reference not given in the LFIS

Eurytemora affinis - Copepod (Map 6)

Description - Eurytemora affinis is a small (1-mm) calanoid copepod of the family Temoridae. It is an abundant organism in the tidal freshwater and oligohaline zones of the Chesapeake Bay.

Range - Eurytemora affinis is an estuarine endemic found in temperate areas. In Chesapeake Bay, Eurytemora is found throughout the year, although it is more abundant and has the greatest range in spring. In summer months, this species is restricted to oligohaline and tidal freshwater areas.

Salinity Relationships - Eurytemora affinis prefers brackish water but has been found in habitats as diverse as freshwater lakes and the ocean (Katona, 1971). In the Chesapeake Bay, it is most abundant in the spring and occupies a salinity range from 0 to about 20 ppt. Maximum abundance, about 50 to 100,000 individuals per m^3, occurs in the area where salinities are less than 10 ppt. As temperatures rise in late spring, the numbers of this species decline, and it disappears from the higher salinity areas. At this time, maximum abundance (about 1000 - 5000 individuals per m^3) is found below 4 ppt. Because of its rather wide salinity tolerance, the habitat criteria used for this species was 5 to 15 ppt. Although Eurytemora is found in the oligohaline zone, the 5 to 15 ppt criterion was selected based on Jefferies (1962) theory that if one-third the length of an estuary includes the 5 to 15 ppt zone during the spring (which the James River does), then Eurytemora will will be one of the dominant zooplankters and that this zone provides recruitment into upstream and downstream areas.

Sensitivity and Potential Habitat - Eurytemora affinis is a species with north temperate origins (Jeffries, 1962), and this is reflected in its reduced range and abundance in summer. Competition with Acartia tonsa was once proposed as the mechanism restricting E. affinis to low salinity regions in warmer months. However, the observed decine in abundance of Eurytemora begins before A. tonsa numbers increase dramatically (Sage, pers. comm.). Competition could still be a factor, however, since A. tonsa has been shown to feed upon the nauplii of E. affinis (Lonsdale et al., 1979). Heinle and Flemer (1975) suggest that predation by fish, especially striped bass, may be a more important factor than salinity in limiting Eurytemora's distribution.

Trophic Importance - Eurytemora affinis is probably the single most important zooplankter in the oligohaline and tidal fresh nursery grounds of many fish. It has been shown to be particularly important to alosids (Burbidge, 1972) as well as moronids (Polgar et al., 1975; Setzler et al., 1979; Beaven and Mihursky, 1980). Abundance of Eurytemora is important for survival of striped bass larvae (Setzler et al, 1979), as it can constitute 72% of their food (Beaven and Mihursky, 1980).

Eurytemora is a selective filter feeder, and feeds upon algae and detritus. Like Acartia, it "tracks" biomass peaks to maximize feeding efficiency, but does not show raptorial feeding on larger particles. When algal production is insufficient to meet carbon requirement for this species, it utilizes detritus (Allan et al., 1976). Delivery of marsh detritus to the lower estuary by spring runoff is important to Eurytemora biomass in this time period.

Selection Factors -

- Trophic importance to larval fish survival.
- Restricted salinity range, and vulnerability to salinity increases.

Sources -

Acad. Nat. Sci. Phila., 1977;1978
Allan *et al.*, 1976
Beaven and Mihursky, 1980
Lippson *et al.*, 1979
Burbidge, 1972
Burrell, 1972
Conte and Otto, 1980
Ecological Analysts, 1974
Goodwyn, 1970
Grant and Berkowitz, 1979
Grant and Olney, 1979
Heinle and Flemer, 1975
Jefferies, 1962
Johns Hopkins University, 1972
Katona, 1971
Knatz, 1978
Lonsdale *et al.*, 1979
Olson and Sage, 1978
Polgar *et al.*, 1975
Sage and Olson, 1977
Sage *et al.*, 1976
Setzler *et al.*, 1979
Storms, 1975

Scottolana canadensis - Copepod (Map 7)

Description - Scottolana canadensis is a harpactacoid copepod of the family Canuellidae. It is an elongate form about 1.5 - 2.0 mm long, typically epibenthic, but seasonally abundant in the zooplankton. In many collections it has been confused with the much smaller Halectinosoma curticorne, also an abundant species in the Bay (Sage, pers. comm.). For this reason, there is a certain amount of conjecture regarding some of its distribution records.

Range - Scottolana is an estuarine endemic species, reaching its greatest abunance in the oligohaline portions of temperate-zone estuaries. In the Chesapeake, Scottolana is most abundant in late spring and summer, and extends its range furthest downstream at this time into low mesohaline regions.

Although considered a benthic species and a member of the meiofauna, there is a great paucity of information on Scottolana's benthic role. It is probable that it overwinters and spends part of its life cycle on the bottom but there is apparently no information as to depth and sediment preferences, if any. This reflects the general lack of knowledge about meiofaunal composition and distribution in Chesapeake Bay.

Salinity Relationships and Potential Habitat - Scottolana reaches its greatest abundance (up to 100,000 individuals per m^3, but usually an order of magnitude less) between the salinities of 1.0 to 5.0 ppt or so. It is found in salinities up to 10 ppt or slightly more, and also in tidal freshwater, but at reduced densities. The extent of this species' range into lowest salinities is uncertain, but it is not a characteristic member of the freshwater zooplankton.

Trophic Importance - Scottolana and other harpacticoids are considered one of the major foods for juvenile sciaenid fishes, as well as other benthic feeders. For example, Stickney et al. (1975) found harpacticoides in 88% of spot stomachs examined, the single most numerous item. The coincidence of Scottolana's range with major nursery areas is of particular importance.

Selection Factors -

- Restricted salinity tolerance of this species, and potential reduction of range under increased salinities.
- Importance as food for demersal feeding juvenile fish, particularly Sciaenids.

Sources -

Acad. Nat. Sci. Phil., 1977;1978
Burrell, 1972
Heinle et al., 1975
Lippson, 1973
Lippson et al., 1979
Sage and Olson, 1977
Stickney et al., 1975

Pectinaria gouldii - Polychaete worm (Map 8)

Description - Pectinaria gouldii* is a large tube-building polychaete of the family Amphictenidae; popularly known as the trumpet worm because of its long conical-shaped tube. The tube is about 2 - 5 cm in length, depending on the size of the animal, and constructed of a single layer of sand grains firmly cemented together. The most notable feature of the animal are the two sets of long golden paleae or setae on the head, which are used for digging or as an operculum for the tube. The head is also equipped with numerous tentacles which are used in feeding and tube building.

Range - Pectinaria gouldii is found from New England to North Carolina in inter- or subtidal areas. In Chesapeake Bay, it is confined to high mesohaline and polyhaline regions. Its distribution is spotty and variable within its range, and densities are usually less than 500 per m^2, although numbers of 4000 per m^2 or more have been recorded (chiefly young worms).

P. gouldii appears to spawn once a year in Chesapeake Bay, probably in late spring (Virnstein, 1979). Larvae are pelagic; they first settle to the bottom and build a small chitinous tube (Watson, 1927). This forms the base of the later adult tube. Recruitment is irregular, but several thousand young worms per square meter may settle in late May or June. Growth is relatively rapid, the worms reaching adult size by autumn (Virnstein, 1979). Loss to predation is high, however, and few worms live to two years of age (Peer, 1970).

Salinity Relationships - There are apparently no laboratory studies of the exact physiological tolerances of P. gouldii, at least in regard to salinity. However, collection information from Chesapeake Bay indicates that it is not found in salinities much below 10 ppt, and is most abundant at 15 ppt or above. This is the expected range of a eurytolerant marine species such as Pectinaria gouldii.

Other Sensitivities - Like all organisms, P. gouldii is affected by temperature. Optimal and lethal temperatures for this species have apparently not been determined, but spawning appears initiated when spring temperatures reach 15°C or so. Rate of sediment working (feeding) and respiration are also temperature-dependent, and reach very low levels in winter (Gordon, 1966; Nichols, 1975).

P. gouldii is also somewhat sensitive to sediment type. Adult worms cannot work particles larger than 1 mm (Gordon, 1966). Also, Watson (1927) reports the death of young worms of the congeneric P. koreni resulting from clogging of the small end of the tube by passage of too-large-sized particles. P. gouldii is generally more abundant in fine sands, muddy sands, and sandy muds (Pfitzenmeyer, 1961; Boesch, 1973).

*Note: Because of confusion about the type specimen for the genus, the name Pectinaria has been recently replaced by Cistena. However, as this change has been appealed to the International Commission on Zoological Nomenclature, the more familiar name is retained for this report.

Anoxic conditions may limit Pectinaria. In Kiel Bay, W. Germany, years in which summer anoxia developed had greatly reduced recruitment of young P. koreni, and near total destruction of standing stock (Nichols, 1976). Wass et al. (1972) report P. gouldii to about 30 meters in Chesapeake Bay, but summer hypoxia in many areas could be expected to reduce or eliminate populations below 15 - 20 meters (Holland et al., 1979).

Potential Habitat - Potential habitat for this species is defined as those areas where salinity is between 15 and 18 ppt, and from 0 to the bottom (R.J. Diaz, pers. comm.).

Trophic Importance - Pectinaria gouldii is a deposit feeder, ingesting detritus and its associated microorganisms, algae, and decaying animal and vegetable matter. Gordon (1966) found that this species removed almost half of the organic matter from each gram of sediment worked (laboratory results). The animal digs vigorously with its paleae, and the loosened sediment is conveyed to its mouth by the cilitated tentacles. Some sediment is rejected, some ingested, while some is worked and then passed through the tube by a vigorous "pumping" action of the worm's body (Watson, 1927). The ejected material is deposited as a small mound at the posterior of the tube.

P. gouldii is a major prey item for bottom feeding fish and crabs and mortality due to predation is heavy. Peer (1970) estimated that 80% of the annual mortality of P. hyperborea was due to predation, and that 70% of a cohort was lost to predation during its first year of life. Virnstein (1979) noted that P. gouldii is usually not abundant in the natural environment, but that it increased several orders of magnitude in exclosure cages. He hypothesized that fish and crab predation are major factors regulating the numbers of this species.

Pectinaria is also an important bioturbator of sediments where it is abundant. In the laboratory, Gordon (1966) determined that each worm works about 6 grams of sediment per day at 18 - 19^{o}C, with the rate decreasing with temperature. At the latitude of Cape Cod, he estimates that one worm would rework 600 grams of sediment annually (in Chesapeake Bay this rate would probably be higher). He finally concludes that at densities of 40 worms per m^2, the sediment would be completely turned over to a depth of 6 cm in four years. Also, where larger particles are mixed with finer sediment, the finer material is carried to the surface and deposited, leaving the coarser material at depth (Gordon, 1966). Thus P. gouldii can also exert a sorting effect on natural substrates.

Selection Factors -

- Potential for range extension under increased salinities.
- Importance as food for demersal fish and crabs.
- Importance as a bioturbator of sediments.

Sources -

Boesch, 1971; 1973; unpubl.
Cory and Dresler, unpubl.
Diaz, 1977
Harman, unpubl.
Holland et al., 1979
Kaufman et al., 1980
Nichols, 1975; 1976
Peer, 1970
Pfitzenmeyer, 1961
Virnstein, 1979
Watson, 1927
Wass et al., 1972

Scolecolepides viridis - Polychaete worm (Map 9)

Description - Scolecolepides viridis is a burrowing polychaete worm of the family Spionidae. Adult worms are about 4 - 10 cm long, green or brownish green in color, with prominant red branchiae, and two stout tentacular palps. It inhabits a mucous-lined burrow, generally in intertidal or subtidal areas.

Range - Scolecolepides viridis is found from Newfoundland to Georgia, in areas of reduced salinity. In Chesapeake Bay, it is confined to the oligohaline through mesohaline regions, chiefly in intertidal or shallow subtidal areas. Densities are generally less than 2000 per m^2, but numbers of 10,000 individuals per m^2 have been recorded.

S. viridis breeds in early spring in Chesapeake Bay, and juvenile worms appear in May through July (Pfitzenmeyer, 1970; Dauer et al., 1980). Eggs and sperm are released from ripe individuals, and planktonic larvae result. George (1966) reported that eggs cannot be fertilized, nor will they develop, at salinities under 5 ppt. This has implications for the species in Chesapeake Bay, as a large proportion of the population is found below these salinities, and Pfitzenmeyer (1970) considers it one of the three characteristic oligohaline species in the upper estuary. Dauer et al. (1980) observed numerous ripe worms swimming at the surface at night on an ebb tide, which they consider a mechanism for dispersing breeding individuals into higher salinity areas. The resulting larvae may then be transported up-estuary by bottom currents to recolonize the oligohaline zone. Larvae metamorphose at about 30 - 40 days of age, becoming negatively phototactic and testing the substrate. They eventually construct a small vertical burrow and begin a benthic existence (George, 1966).

Salinity Relationships - Scolecolepides viridis is a characteristic species of the upper Bay, although it has been found regularly in upper mesohaline areas, and even occasionally in the polyhaline zone (Dauer et al., 1980). Salinity is probably not the adult downstream limit, as much as predation or competition. Adults have been collected in salinities as low as 0.5 ppt, and occur with frequency up to 15 ppt or so. Maximum densities occur generally between 1 - 5 ppt in the Bay.

Larvae, as was discussed above, have definite minimum salinity limits. Eggs cannot be fertilized or early egg cleavage takes place below 5 ppt, although older larvae can survive 2.5 ppt. Eggs develop normally up to 30 ppt.

Other Sensitivities - S. viridis is affected by temperature both in regard to spawning and development, and probably summer survival. It is a boreal and north temperate species, and may be limited by summer temperature at the latitude of Chesapeake Bay. Holland et al. (1980) record that its abundance is at a minimum in summer. George (1966) found that larvae need temperatures of at least 2°C to begin development, and of 10°C to reach metamorphosis. Upper temperature limits for both adults and larvae appear to be between 34 - 35°C.

S. viridis is most numerous in firm substrates which allow tube building, although it has been recorded from virtually all sediment types. Pearson and Bender (1975) found that it was more tolerant of excess siltation than some other upper Bay species.

Potential Habitat - Potential habitat for this species is defined as areas between 1 and 15 ppt, in all substrate types and at all depths.

Trophic Importance - Scolecolepides viridis is an infaunal deposit feeder, ingesting detritus, algae, microorganisms, small meiofauna, and decaying animal and vegetable matter. The worm inhabits a vertical mucous-lined burrow in firm substrates, and feeds upon the surface deposits surrounding its tube. The ciliated tentacles carry food to the pharynx, where it is ingested. The animal was abundant in organically-enriched substrates in Baltimore harbor, including mud, so it should be considered a relatively pollution-tolerant species (Pfitzenmeyer, 1975).

S. viridis is fed upon by fish, crabs and benthic invertebrate predators such as Nereis. Holland et al. (1980) suggest that the temporal pattern of the species at Chalk Point indicates its standing stock is controlled by predation; numbers are lowest when predators are most abundant. Caging experiments at Calvert Cliffs show that numbers inside the exclosure are significantly higher than controls only in summer (Holland et al., 1979). The lower numbers observed inside the cages at other times may reflect "internal" predation by species such as Eteone or Nereis. Homer and Boynton (1978) found that S. viridis is an important item in the diet of spot and winter flounder, and is eaten by other bottom feeding species.

As with all tube-building species, S. viridis contributes to sediment stabilization, sorting, and aeration.

Selection Factors -

- Sensitivity of reproductive cycle to salinity, and importance of estuarine circulation patterns to distribution of the species in the oligohaline zone.

- Abundance of the species in low salinity areas, and food potential for fish, crabs, birds and other predators.

Sources -

Boesch, 1971, unpubl.
Cory and Dresler, unpubl.
Dauer et al., 1980
Diaz, 1977; pers. comm.
Ecological Analysts, Inc., 1979
George, 1966
Hawthorne, 1980
Holland et al., 1980
Homer and Boynton, 1978
Lippson, A.J. et al., 1979
Lippson, R.L., unpubl.
Pearson and Bender, 1975
Pfitzenmeyer, 1970; 1975
Reinharz et al., 1979
Robinson, 1978

Urosalpinx cinerea - Oyster drill (Map 10)

Description - Urosalpinx cinerea is a small snail of the family Muricidae. It is about 1.5 - 2.5 cm long, fusiform in shape, with a moderately high-spired shell crossed by numerous rounded folds. The shell is greyish, brown, or yellowish in color with a white, brown or purple aperture.

Range - U. cinerea is found from the Maritime provinces to Florida along the western side of the Atlantic. It has also been introduced on the west coast of North America and Great Britain. In Chesapeake Bay the oyster drill is confined to the high mesohaline and the polyhaline zone. Urosalpinx occurs from the intertidal zone to deep water, limited chiefly by availability of appropriate substrate and prey. It is found most abundantly on pilings, rocks, reefs, and on shells or oyster beds. Numbers may rarely reach 200 individuals or more per square meter, but 2-20 is a more typical range.

Urosalpinx spawns in the warmer months, from about May through October in Chesapeake Bay. Sexes are separate in this species, and they have internal fertilization. Sperm from a single copulation can remain viable for extended periods (Stauber, 1943). About 5 - 20 eggs are laid at a time, enclosed in characteristic whitish to yellow-brown urn-shaped egg capsules about 5-10 mm long. Several egg cases may be deposited at once on hard substrates. The incubation period varies with water temperature, but ranges from 25 - 45 days or more (Carriker, 1955). Small protoconches (about 1 mm high) emerge and begin to feed on small bivalves or barnacles. Sexual maturity is reached in about 15 - 25 months, and individuals may live 10 years or more. Because of the non-planktonic larvae and relatively slow rate of reproduction, drills are slow to recolonize areas from which they have been eliminated (by freshets, for example).

Salinity Relationships - Salinity has a critical influence on the distribution of Urosalpinx. Minimum salinity for survival appears to be near 11 ppt; and feeding is greatly reduced below 12.5 ppt (Manzi, 1970). Optimum salinities are about 15 - 35 ppt (Carriker, 1955). Because of the low mobility of this species, the minimum salinity at any particular spot during the year determines Urosalpinx's presence or absence. Thus in nature, relatively stable "drill lines" existed in the main Bay and tributaries: Towles Point on the Rappahannock, Claybank on the York, Brown Shoals on the James, and Tangier Sound on the eastern shore. After tropical storm Agnes, however, the species was eliminated from much of its range (Andrews, 1973), and has not yet recovered (Haven, pers. comm.). Low salinities at time of egg-laying have the greatest effect on distribution (Haskin, 1974).

Other Sensitivities - Temperature also has an effect on the distribution of Urosalpinx. Drills become inactive, and may burrow into the bottom, when water temperatures drop below 8 - 10°C. (There is considerable geographic and individual variation in this response). Oviposition begins at around 15°C; although again, there is considerable variation. There is a synergistic effect of temperature and salinity observed by several investigators: mortality decreases at low salinities when water temperatures are also low (Stauber, 1943; Manzi, 1970). This enhances Urosalpinx survival during spring months when runoff is highest, and water temperatures still are low.

Urosalpinx is found chiefly on hard substrates, and oviposition can only take place in such areas.

Potential Habitat - Potential habitat for this species is mapped to a depth of about 10 m, where suitable substrate exists and at salinities from 12.5 to 34 ppt.

Trophic Importance - Urosalpinx cinerea is a carnivorous snail and preys upon shelled invertebrates, especially small bivalves and barnacles. Shell of the prey is penetrated by mechanical action of the radula, aided by secretions of the accessory gland, and the flesh of the prey rasped out. Urosalpinx in Chesapeake Bay appears to feed primarily on barnacles, oyster spat, and the smaller stages of other bivalves such as Mya, although it has ben shown to prey upon other Urosalpinx, mussels, bryozoans, crabs, and carrion.

Urosalpinx represents one of the principal predators of young oysters and spat. In high salinity areas they can cause serious destruction of planted seed, up to 60 - 70% (Galtsoff, 1964).

Selection Factors -

- Possible range extension resulting from increased salinities.
- Importance as a predator of small oysters and planted seed.
- Importance of freshets in establishing upstream limits of distribution.

Sources

Allen, 1958
Andrews, 1973
Carriker, 1955
Galtsoff, 1964
Haven et al., 1975; 1977; 1979; pers. comm.
Lippson, 1973
Manzi, 1970
Stauber, 1943
Zachary and Haven, 1973

Crassostrea virginica - American oyster (Map 11)

Description - *Crassostrea virginica* is a large epifaunal bivalve mollusk of the family Ostreidae. Adults range from 75 - 150 mm or more in length, irregularly elongate, with a somewhat cupped lower valve cememted to the substrate. The shape and size of this species varies greatly with growing conditions.

Range - The American oyster ranges from New England through the Gulf Coast states, in both estuarine and marine waters. It is found attached to a variety of hard substrates (pilings, rocks, oyster shell, firm sand, mud, etc.) in the intertidal to subtidal zones; in many areas extensive reefs or beds are formed. In higher salinity water, predators may eliminate subtidal populations. In Chesapeake Bay, *Crassostrea virginica* is found from the low mesohaline through the polyhaline zone, primarily in shallow water (less than 8 - 10 meters deep). Densities vary, depending on the type of substrate, from 10 - 100 or more individuals per m^2. Numbers of oysters reaching 1000 or more per m^2 have been recorded in dense intertidal beds along the Gulf coast (Dame, 1972).

Oysters spawn during warmer months, when water temperatures are over 15°C. The peak period is typically from mid-July to August (Galtsoff, 1964). The exact time of peak spawning and setting can vary from area to area and from year to year, depending on hydrographic conditions. Sperm and eggs are released into the surrounding water, and free-swimming planktonic larvae result. Time to setting of the larvae varies with temperature, and may be as short as 7 - 10 days under optimal conditions. Spat set is highest on clean, sediment-free surfaces, while survival is best in areas with low numbers of predators (such as *Urosalpinx*, *Rhithropanopeus*, or *Callinectes*). Oysters reach harvestable size in 2 to 3 years, and may live 10 years or more.

Crassostrea is limited in higher salinity Chesapeake Bay areas by predators to a certain extent, and by two protozoan parasites, *Minchinia nelsoni* ("MSX") and *Perkinsus marinus* ("dermo").

Salinity Relationships - *Crassostrea virginica* is an euryhaline species, tolerant of a wide range of salinities from 6 - 7 ppt to 35 ppt. Minimum salinity for survival is 5 ppt in the laboratory, although it can withstand lower salinities for short time periods (Castagna and Chanley, 1973). Survival is normal at 7.5 ppt or higher (Loosanoff, 1952). Acclimation may play an important role in response to salinity stress. Chanley (1958) found optimum growth of larvae between 12.5 and 25 ppt. However, reproduction occurs at different salinities depending upon the acclimation of the adult animals: Davis (1958) found eggs spawned at low salinities (7.5 - 10 ppt) to develop normally, while eggs from adults held at higher salinities had higher development optima. Lower salinities reduce the range of temperature tolerance for development (Davis and Calabrese, 1964). Increase of salinity may enhance setting and survival in upstream oyster bars (Kranz, pers. comm.), although new predators may be introduced.

Other Sensitivities - In its normal estuarine environment, *Crassostrea* tolerates a wide range of temperatures. Adult oysters can withstand temperatures as low as 1^{o} C and in excess of 35^{o}C. However, below 6 - 7^{o} C, *Crassostrea* ceases feeding (Galtsoff, 1964). Developmental stages have more restrictive requirements. Gametogenesis is initiated at 15^{o}C, and peak spawning occurs about 20^{o} in Chesapeake Bay. Normal development of eggs and larvae occurs between 20 - 32^{o}C, with fastest growth at higher temperatures (Davis and Calabrese, 1964). Low salinities narrow this tolerance range.

Oysters are also sensitive to turbidity and sedimentation. Excessive sediment smothers adult oysters and prevents setting of spat. Deposition of sediment within historic times has shifted the upstream limit of oyster distribution downstream several miles (Alford, 1968). Areas of good circulation, therefore, are best for oyster setting and survival.

Oyster larvae have been shown to utilize the upstream flow of higher salinity water at depth to maintain themselves within the estuary, and to reach upstream oyster beds (Hargis and Wood, 1971). In addition, shear zones at frontal areas may be sites of accumulation (and recruitment) of bivalve larvae (Hartwell and Savage, 1980). Circulation changes may reduce the impact of these mechanisms, possibly affecting recruitment.

Like most benthic species, oysters are limited in depth by dissolved oxygen concentrations. In the Chesapeake, most oysters are found in less than 10 meters depth; where circulation is good, distribution may extend to much greater depths (Merrill and Boss, 1966).

A major factor affecting density and abundance of oysters in Chesapeake Bay are predation and disease (actually, protozoan parasites). *Minchinia nelsoni* ("MSX") was introduced to the Bay in the late 1950's to early 1960's, and caused extensive mortality in higher salinity areas. This sporozoan is most important in salinities over 14 - 15 ppt, and remains a major limit to oysters in these waters. *Perkinsus marinus* (formerly *Dermocystidium* or "dermo") occurs in lower salinities than MSX, and is highly infective during warmer months (when salinities tend to be high). Kranz (pers. comm.) has found active "dermo" infections in oysters at 10 - 11 ppt. Several major predators, in particular the drills *Urosalpinx* and *Eupleura*, are also restricted to higher salinities.

Potential Habitat - Potential habitat for this species is mapped at salinities of 7.5 to 34 ppt, at depths of 0 to 10 meters, and in all sediment types where suitable hard substrate occurs.

Trophic Importance - *Crassostrea virginica* is an epibenthic suspension feeder, ingesting algae, bacteria, and small detrital particles. The majority of particles ingested are in the 1 - 12 range, with 1 - 3 the largest single size fraction (Haven and Morales-Alamo, 1970); this is in the range of nannoplankton and bacteria. An oyster weighing one gram (dry weight) will pump and clear approximately 6 liters per hour, although rate depends on temperature. Particles filtered but not ingested are eliminated as pseudofeces. Fecal and pseudofecal material is important in sediment production and deposition, provides sites for remineralizing bacteria action, and represents a source of food for deposit feeders. In warmer months, an oyster may deposit 1.5 grams or more of feces and pseudofeces per week (Haven and Morales-Alamo, 1967).

Oysters are a major commercial species in Chesapeake Bay, and although harvests are reduced compared to historical levels, they still represent a significant economic contribution. Transportation of seed from areas of good recruitment to areas where growth is good and loss to predation and disease reduced is widely practiced. In the future, oyster culture and harvest will probably become more managed, with less reliance on natural recruitment.

Selection Factors -

- Sensitivity to salinity related stratification and sedimentation, which could be affected by the project.
- Effects of disease and predation in higher salinity areas.
- Commercial importance.

Sources -

Alford, 1968
Andrews, 1967
Castagna and Chanley, 1972
Chanley, 1958
Dame, 1972
Davis and Calabrese, 1964
Galtsoff, 1964
Hargis and Wood, 1971*
Hartwell and Savage, 1980
Haven and Morales-Alamo, 1967; 1970
Haven et al., 1978; 1979; pers. comm.
Larsen, 1974
Lippson, 1973
Lippson et al., 1979
Loosanoff, 1952
Merrill and Boss, 1966
Yates, 1913

* Reference not given in the LFIS

Mercenaria mercenaria - Hard Clam (Map 12)

Description - Mercenaria mercenaria is a large bivalve of the family Veneridae It is about 10 cm or less in length, with oval somewhat arched valves, strong umbones, short siphons, and a wedge-shaped foot. The shell is grey, white, or cream exteriorly, with a white interior and rich purple markings near the posterior and ventral margins.

Range - The hard clam is abundant near shore from the Gulf of St. Lawrence to the Gulf of Mexico, and in European waters. In Chesapeake Bay it is found in the lower Bay, from the upper mesohaline through the polyhaline zones. Although found in a wide variety of sediment types, Mercenaria is most abundant in firm substrates.

Mercenaria spawns when water temperatures reach 22 - 24°C, and larvae set in the summer months. The species is long-lived, and recruitment to some populations (especially those existing near the lower limits of salinity tolerance) may be infrequent.

Salinitiy Relationships - M. mercenaria is a euryhaline marine species and is limited by salinity. Adult clams cannot survive salinities much below 12 - 12.5 ppt, and growth of juveniles ceases below 17.5 ppt (Castagna and Chanley, 1973). Larvae fail to metamorphose below 17.5 ppt, and the range of salinity for normal egg development is 20 - 35 ppt (Davis, 1958).

Other Sensitivities - Wells (1957) found that the abundance of hard clams was correlated with substrate, and that sediment preference followed this order: shell, sand, sand/mud, mud. Abundance in shell may be related to larval setting behavior, as the larvae prefer to attach their byssus to a firm substrate lightly covered by sediment.

Temperature also affects this species. The minimum temperature necessary for spawning (22 - 24°C) may limit Mercenaria in the northern part of its range. Davis and Calabrese (1964) found the optimum temperature for growth of clam larvae was 25 - 30°C.

Freshets occurring during spawning periods could affect larvae both through direct salinity stress and by flushing them from the estuary.

Potential Habitat - Potential habitat for this species is defined as areas in greater than 17 ppt salinity, in depths between 1- 15 meters. Highest abundance is in sand and muddy sand. The species is mapped in its summer distribution pattern.

Trophic Importance - Mercenaria mercenaria is a shallow-burrowing infaunal suspension feeder, ingesting detritus and phytoplankton. In turn, it is food for a number of fish, crabs, and waterfowl, although the large size and solid shell of the fully adult clam afford it a measure of protection. Gulls and rays feed upon the adult clams, the former dropping them from height to crack the shell; the latter relying on their powerful dental pavement to crush the clam (Hibbert, 1977; Orth, 1975). Juveniles and newly set spat are preyed upon by crabs, demersal fish, and waterfowl.

The hard clam is also a commercially important species, although harvests in the Bay are limited by irregular recruitment (itself due to low salinities). Areas which support harvests include the lower York River, Poquoson Flats and Willoughby Banks. Transfer of young clams from areas of good recruitment (or from hatcheries) to regions suitable for growth has potential to increase the fishery. Higher salinities might produce a larger and more stable popluation of *M. mercenaria* in the Bay, although increase of certain predators such as the whelk, *Busycon*, could also result.

Selection Factors -

- Distribution limited upestuary by salinity and potential for range increase.
- Commercial importance.

Sources -

Allen, 1954
Boesch *et al.*, 1973
Castagna and Chanley, 1973
Davis, 1958
Davis and Calabrese, 1964
Haven *et al.*, 1975; 1977; 1979; pers. comm.
Hibbert, 1977
Lippson, 1973
Orth, 1975
Pfitzenmeyer, 1961
Wells, 1957

Macoma balthica - Baltic macoma (Map 13)

Description - Macoma balthica is a small clam of the family Tellinidae. It is usually less than 3.0 cm in length, with a thin oval shell of white or pinkish exterior and rose-red interior.

Range - This species is circumboreal in distribution, and is found from the Arctic to approximately Georgia on the west coast of the Atlantaic. M. balthica is most abundant in estuaries, sheltered bays, and similar brackish environments, and may be replaced in higher salinity areas by the congeneric M. tenta (south of Cape Cod). M. balthica is one of the major mollusks in Chesapeake Bay, and may reach densities of 2000 invidivuals per m^2 or more, although numbers an order of magnitude smaller are more usual. It lives as an infaunal species in muddy sands and softer substrate, and feeds upon detritus. M. balthica exhibits two periods of recruitment each year, corresponding to April - mid-June and August - November spawning seasons, a pattern typical of species of boreal affinities.

This species is long-lived and in cold waters may live 10 years or more. Longevity in the Bay is probably half that.

Salinity Relationships - Macoma balthica can tolerate salinities from 2.5 ppt to full oceanic values in the laboratory; however, in nature it is most abundant below 25 ppt (Castagna and Chanley, 1973). In Chesapeake Bay, M. balthica is generaly found below 18-19 ppt. Its distribution may be mediated by competition with M. tenta (Boesch, 1971).

Other Sensitivities - M. balthica appears relatively tolerant of sediment type, being found from mud to fine sand, although most abundant in softer substrates. Spawning periods are mediated by water temperature; in Chesapeake Bay the period of spawning corresponds to water temperatures between 15 - 22°C. Like all Chesapeake Bay benthic species, M. balthica is sensitive to the typical summer hypoxia in deep waters, and for this reason is generally found in less than 12 - 15 meters depth. However, in areas with good circulation and high dissolved oxygen, it may be found at greater depths.

Potential Habitat - This species' potential habitat is defined as areas between 5 and 18 ppt salinity and between 1 and 5 meters deep. Mapping is for fall distribution, after the autumnal recruitment period.

Trophic Importance - Macoma balthica is an infaunal deposit feeder, ingesting material through use of its long active incurrent siphon. It also ingests a certain percentage of suspended material near the sediment-water interface. Productivity of M. balthica is usually highest where bacterial productivity on detrital particles is also high (Tunniclife and Risk, 1977).

Because of its abundance, M. balthica is an important source of food for demersal fish, crabs, and waterfowl (Homer and Boynton, 1978; Holland et al., 1979). Perry and Uhler (1976) found that M. balthica now represents about 95% of the food of canvasback ducks, probably due to the great reduction in submerged aquatic vegetation in recent years. The great di'ferenes in density of M. balthica between caged and uncaged bottom areas (31,000 per m^2 vs. 733.6 per m^2 in July) shows the effects of predation on this important species.

Selection Factors -

- Trophic importance as source of food for variety of organisms.

- Potential reduction of range due to increased salinity.

Sources

Boesch, 1971; unpubl.
Castagna and Chanley, 1973
Cory and Dresler, unpubl.
Davies, 1972
Diaz, 1977; pers. comm.
Ecological Analysts, 1974
Harman, unpubl.
Hawthorne, 1980
Holland *et al.*, 1979; 1980
Homer and Boynton, 1978
Johns Hopkins U., 1972
Kaufman *et al.*, 1980
Lippson *et al.*, 1979
Lippson, R.L. unpubl.
McErlean, 1964
Perry and Uhler, 1976
Pfitzenmeyer, 1961; 1970; 1975
Reinharz *et al.*, 1979
Tunniclife and Risk, 1977

Balanus improvisus - Acorn barnacle (Map 14)

Description - Balanus improvisus is a small barnacle of the family Balanidae. It is about 0.5 to 1.5 cm in diameter; its shell a low cone formed of six overlapping somewhat triangular opercular valve plates.

Range - Balanus improvisus is common in the low intertidal and subtidal zones, primarily in lower salinity water, in temperate and subtropical areas worldwide. In Chesapeake Bay it is most abundant in the oligohaline and low mesohaline areas, but can occur into the polyhaline zone. Densities can reach 50,000 individuals per m^2 or more under favorable conditions.

Acorn barnacles exhibit two periods of setting in many Chesapeake Bay areas. Calder and Brehmer (1967) found a heavy set at Hampton Roads in May, with another recruitment in October. However, Branscomb (1976) reports only a spring set in 1972, the year of Tropical Storm Agnes.

Barnacles are hermaphroditic, but cross-fertilization is the rule. B. improvisus spawns in spring and fall in Chesapeake Bay. The eggs are brooded in the mantle cavity, and the larvae released as nauplii which have a characteristic horned, triangular carapace. The nauplii metamorphose into the bivalve cyprid larvae, which seek out and attach themselves to hard substrates by a short stalk. Further metamorphosis occurs to produce the typical adult shape. Barnacles reach adult size in approximately four to six months, depending on water temperature, availability of food, and crowding effects. There is often heavy mortality due to predation, spatial competition, and in winter, effects of cold and dessication (Branscomb, 1976).

Barnacles are principal fouling organisms in marine areas. B. improvsis, one of the dominant species in Chesapeake Bay, is important in bio-fouling of ships, pilings and other structures, water intake and condensor tubes, as well as oyster beds. For this reason, considerable effort has been devoted to study and control of barnacles and other fouling species.

Salinity Relationships - B. improvisus is a relatively eurytopic species in respect to salinity. It occurs in nature in salinities as low as 2 ppt, and up to 20 to 24 ppt (Gordon, 1969). Turpaeva and Simkina (1961) found optimum growth of this species in the Black Sea occurred at 5 to 11 ppt, which corresponds generally to its major abundance in Chesapeake Bay. It is able to withstand lower salinities for short periods, as Larsen (1974) reported it year round at a station where salinities dropped in spring to 0.7 ppt.

B. improvisus is, however, seriously impacted by predators--some of which are limited to higher salinities. The flatworm Stylochus ellipticus is a major cause of summer barnacle mortality (Branscomb, 1976); it is rarely found below 9-10 ppt in nature (Larsen, 1974). In the laboratory, Landers and Rhodes (1970) found Stylochus to be able to survive and feed at salinities of 5 ppt or above, so the apparent salinity limit of its realized range may reflect reproductive stress.

Other Sensitivities - B. improvisus is sensitive to low winter temperatures, particularly when in conjunction with high winds. The combination of these two factors accounts for a major part of intertidal barnacle mortality in Chesapeake Bay (Branscomb, 1976). Recolonization of the intertidal zone apparently results from surviving subtidal populations.

In addition to predators such as Stylochus, Urosalpinx, and crabs, barnacles are affected by competition for space. The bryozoan Victorella pavida is a major spatial competitor, smothering the barnacles (Branscomb, 1976).

Balanus is restricted to hard substrates, and occurs on rocks, pilings, bivalve and crustacean shells, and so forth. Anoxia in summer may reduce or eliminate individuals in depths greater than 10 m, although the species can be found to 15 m or so.

Potential Habitat - Potential habitat for this species is defined as areas between 5 to 20 ppt and below 1 meter when hard substrate exists. Over 10 ppt, the species is reduced by predation.

Trophic Importance - B. improvisus is an epibenthic suspension feeder, and ingests bacteria, detritus, algae, and small zooplankters. They are capable of selective feeding, and show a preference for animal food (Kuznetsova, 1973; 1978). They may also ingest the larvae of invertebrates, including barnacle nauplii.

Barnacle nauplii may constitute a significant portion of the zooplankton at some times of the year or in certain areas (Herman et al., 1968). At such times they can become a source of food for planktivorous fish, larvae, and suspension feeding invertebrates.

Selection Criteria -

- Sensitivity to predation in higher salinities.
- Biomass and economic importance as a fouling organism.

Sources -

Branscomb, 1976
Calder and Brehmer, 1967
Diaz, 1977; pers. comm.
Gordon, 1969
Harman, unpubl.
Herman et al, 1968
Kennedy and DiCosimo, 1983
Kuznetsova, 1973; 1978
Landers and Rhodes, 1970
Larsen, 1974
Lippson et al., 1979
Lippson, R.L., unpubl.
Turpaeva and Simkina, 1961

Cyathura polita - Isopod (Map 15)

Description - *Cyathura polita* is a moderate sized isopod of the family Anthuridae. It is about 12 - 20 cm in length, with a narrow elongate body, the first pair of legs subchelate and modified for grasping, the other six pairs similar and used for walking and burrowing. Color varies with substrate, but is typically greyish-brown.

Range - *C. polita* is found along the Atlantic and Gulf coasts, chiefly in estuarine waters, from Maine to Louisiana. In Chesapeake Bay it is found from oligohaline to mid-mesohaline areas, although in other parts of its range it has been found under hypersaline conditions (Burbanck, 1967). The species builds tubes in stable substrates. Numbers may reach 1000 per m^2 or more under favorable conditions, although less than 500 per m^2 is a more typical density.

C. polita broods its young in a marsupium, and fertilization is internal. Gravid females are found only in warmer months in the northern part of the species' range, while reproduction is year-round in subtropical areas (Burbanck, 1967). Juvenile animals live interstitially in the substrate. Animals are believed to live about three years. There is evidence that protogynic hermaphrodism is common in *C. polita*; that is, the animal functions as a female in its second year, and a male in the third (Burbanck and Burbanck, 1974). In Florida, Kruczynski and Subrahmanyam (1978) found juveniles maturing sexually in one year, and living only two years. *Cyathura* do not range widely, and most individuals spend their life within a few square meters.

Salinity Relationships - *C. polita* adults are found in a wide range of salinity from fresh or near fresh water, to full salinity, and even (for part of the year) hypersaline conditions. In the northern part of its range, it is more common at full salinity. However, in Chesapeake Bay, the species occurs mainly below 12 ppt. Laboratory experiments have shown adults can survive a range of 0 - 40 ppt or more for several hours (Kelley and Burbanck, 1972).

In the laboratory, embryos of *C. polita* develop normally only between 0.5 - 20 ppt, while at 30 ppt, larvae develop normally but embryos die (Kelley and Burbanck, 1976). The distribution of this species thus probably reflects the sensitivity of the embryo. However, competition or predation may also affect the species' occurrence in Chesapeake Bay.

Other Sensitivities - *C. polita* constructs tubes in stable substrates to a depth of 7 cm or so. It is most numerous in sand, shell, firm clays, and silty sand sediments and less numerous or absent in soft muds (Kruczynski and Subrahmanyam, 1978). The species is sensitive to low dissolved oxygen, which further limits its distribution in unstable muds and in deep water (Burbanck, 1967). *C. polita* is found in salt marshes, intertidally, and subtidally to depth, until restricted by summer anoxia or hypoxia.

Adult *C. polita* are tolerant of a wide range of temperatures, reflected in their boreal-subtropical distribution. Reproduction, however, occurs in warmer months, generally April - August in most of its range. There is evidence that extremes of temperature limit osmoregulatory ability, and that this is most pronounced in southern populations (Burbanck, 1967).

Potential Habitat - Potential habitat for this species is defined as areas between 0.5 - 12 ppt salinity, with highest densities occurring between 1 and 7 ppt, in all substrate types, down to approximately 6 meters depth.

Trophic Importance - *Cyathura polita* is an omnivorous feeder, ingesting detritus, algae, dead animal matter, and small organisms. Since in some habitaits it represents the most numerous benthic species, it probably contributes significantly to transfer of material and energy from detritus to other food webs. *C. polita* has been shown to be used as food by numerous species of fish throughout its range (Burbanck, 1963), and it is probably also preyed upon by crabs. Predation by fish has been cited as one cause of the species' summer decline in many areas (Burbanck, 1967).

Holland *et al.* (1980) found *C. polita* poulations to increase inside predator exclusion cages during summer months. *C. polita* appeared as an important item in the diet of juvenile weakfish and other bottom feeding species collected near Calvert Cliffs, although the isopod is not an abundant member of the benthos there (Homer and Boynton, 1978; Holland *et al.*, 1979).

Selection Factors -

- Importance to detrital food web and as food for fish.
- Sensitivity of embryonic stages to higher salinities.

Sources:

Boesch, 1971
Boesch *et al.*, 1976
Burbanck, 1963; 1967
Burbanck and Burbanck, 1974
Cory and Dresler, unpubl.
Diaz, 1977; pers. comm.
Ecological Analysts, Inc., 1979
Harman, unpubl.
Hawthorne, 1980
Holland *et al.*, 1979; 1980
Kelley and Burbanck, 1972; 1976
Kruczynski and Subrahmanyam, 1978
Lippson, R.L. unpubl.
Pfitzenmeyer, 1970; 1975
Reinharz *et al.*, 1979
Robblee, 1973
Robinson, 1978

Ampelisca abdita - Amphipod (Map 16)

Description - Ampelisca abdita is a burrowing amphipod of the family Ampeliscidae. The body is of generally typical amphipod shape, about 5 - 8 mm in length, with females somewhat smaller. The antennae and pereiopods are modified for feeding. This is a fairly recently described species (Mills, 1964), and in many earlier collections it was confused with its sibling species A. vadorum or other congenerics.

Range - A. abdita is found from the boreal region of Maine at least to the western Gulf coast, excepting southern Florida. In Chesapeake Bay, it is found in the high mesohaline through the polyhaline zones. Densities typically are less than 2000 per meter^2, but accumulations of 30,000 per m^2 or more have been recorded. Mills (1967) characterizes this species as successful in crowded conditions because it grows rapidly and breeds early.

Ampelisca abdita inhabits a tube for the greater portion of its life, save for a brief free-swimming period during reproduction. The tube is constructed of fine sand grains glued together with a secretion from the first two pairs of pereiopods, which hardens to a parchment-like material. The tube is about 3 - 4 cm long, flattened laterally, and rather flexible.

Reproduction is linked to water temperature, and 8 - 10^{o}C seems to be the initiating temperature. Overwintering animals reaching sexual maturity in spring leave their tubes and swim about, particularly at times of spring tides and full moon. Mature males grasp mature females and carry them about; the female then molts and copulation occurs. Mature males die soon after mating, but females return to the substrate to brood their eggs. Females produce only one brood in their lifetime. Young animals disperse and build small tubes. They grow rapidly, building larger and larger tubes, and reach sexual maturity by mid-summer. Their offspring overwinter, growing more slowly, and breed the following spring.

Salinity Relationships - There are apparently no laboratory studies delineating the exact physiological salinity tolerances of A. abdita. However, field collections in Chesapeake Bay indicate that the species is confined generally to areas above 12 ppt (e.g. Boesch, 1971; unpubl.; Wass, 1972).

Other Sensitivities - Temperature affects A. abdita in regard to both growth rate and reproduction. As previously mentioned, 10^{o}C appears to be the initiating temperature for reproduction. South of Cape Hatteras, where winter temperatures remain high, breeding occurs throughout the year (Mills, 1967). Growth, however, can occur in temperatures as low as 3 - 4 ^{o}C. Thus overwintering individuals may attain much greater size than summer broods.

The distribution of A. abdita is influenced by sediment type. In general, it is most numerous in fine sediments, including fine sand, silts, and clays. Its sibling species, A. vadorum, is considerably larger and better adapted to coarse substrates (Mills, 1967; Watling and Maurer, 1972). The two species may occur together, but generally densities are then low, suggesting competition (Mills, 1967).

A. abdita has been recorded from the intertidal to depth, in Chesapeake Bay; however, it appears to occur primarily subtidally. This probably reflects sediment preferences. Feeley and Wass (1967) record it as the most numerous ampeliscid in lower Chesapeake Bay. It occurs seasonally in submerged aquatic vegetation beds, primarily during reproductive periods (Marsh, 1970; Orth, 1973).

Potential Habiat - Potential habitat for this species is defined as areas between 18 and 32 ppt salinity, below 1 meter in depth, most abundant in muddy sands, sandy mud, and mixed sediments.

Trophic Importance - A. abdita is considered a suspension feeder, ingesting suspended detritus, algae, and algae attached to sand grains, although it also resuspends sediment from the bottom, and thus ingests deposited material. The animal feeds at the top of its tube, ventral surface uppermost. The pleopods and second antennae beat and whirl rapidly, setting up feeding currents over the mouth parts.

A. abdita is in turn fed upon by various birds, fish, and other predators. It is sometimes extremely dense, and its tubes constitute a major feature of its habitat. The tubes not only help bind the substrate, they provide shelter and attachment for numerous other species. Mills (1967) noted that fine sediments accumulated around the tubes, providing food for deposit feeding species. In addition, the animal's activity keeps the sediment oxygenated to the depth of the tube. Chlorophyll values were also about two times greater than in a nearby tueless area (Mills, 1967).

Selection Factors -

- Potential for increase under increased salinity.
- Abundance, and importance in binding soft sediments, providing shelter for other species, and oxygenation of substrate.

Sources

Boesch, 1971; 1972; 1973; 1977; unpubl.
Bousfield, 1972
Diaz, 1977; pers. comm.
Feeley, 1967
Marsh, 1970
Mills, 1964; 1967
Orth, 1973
Reinharz et al., 1979
Watling and Maurer, 1972
Wass, et al., 1972

Leptocheirus plumulosus - Amphipod (Map 17)

Description - Leptocheirus plumulosus is a moderate-sized burrowing amphipod of the family Photidae. It is about 10 - 13 mm in length, and of typical amphipod outline, with heavily plumose setae on the gnathopods and perieopods. It inhabits a tube constructed of sand grains and debris.

Range - Leptocheirus plumulosus has been reported from Cape Cod to northern Florida, chiefly in estuaries and tidal ponds. In Chesapeake Bay, it is found from oligohaline waters to the upper mesohaline zone, primarily in shallower areas. It is often quite abundant, and densities of 3000 - 4000 m^2 are not uncommon, while 10,000 or more individuals per square meter have been recorded. Pfitzenmeyer (1970) characterized L. plumulosus as one of three permanent dominant upper Bay species (the others being Cyathura polita and Scolecolepides viridis).

L. plumulosus breeds in the warmer months, mostly during the period May through September, although Pfitzenmeyer (1970) found ovigerous females in October. Adults leave their burrows and a male grasps the female, which may be carried for a while before mating. The female broods the eggs, there are no planktonic stages, and development is direct. Each female produces two broods a year (Bousfield, 1972). The young of the year overwinter, to breed the following spring. Densities of L. plumulosus are generally highest in winter and early spring, and lowest during summer and fall (Holland et al. 1980). This may reflect both the action of predators, and the death of adults after breeding.

Salinity Relationships - There apparently exists no laboratory information on the exact physiological tolerances of L. plumulosus. However, collection information indicates that it is generally restricted to areas where salinity is less than 15 ppt, and reaches greatest abundance from about 1 to 10 ppt.

Other Sensitivities - No information is available on the exact temperature tolerances of L. plumulosus. Breeding, however, is apparently initiated in spring when water temperatures exceed 15°C or so.

L. plumulosus is found in all soft sediments: fine sand, muddy sand, sandy mud, and mud, as well as debris. Boesch et al. (1976) say that its preferred habitat is in shallow sand bottoms in oligohaline areas, but collection records report it in other sediments as well (Pfitzenmeyer 1970, Ecolog. Analysts 1974; Holland et al. 1979, 1980; and others). In hard substrates (firm sands, gravel, shell) it is replaced by another tube-building amphipod, Corophium lacustre. The species is adversely affected by sedimentation, which interferes with feeding. Garety et al. (1975) noted that excess siltation following Tropical Storm Agnes limited L. plumulosus populations, and Bousfield (1972) notes that it occurs in areas with good circulation.

The species is definitely more abundant in shallow areas, which may reflect sediment preference, or sensitivity to summer hypoxia in deep waters. Although recorded to depths of 15 m, it is most abundant in areas less than 10 meters.

Potential Habitat - Potential habitat for this species is defined as areas 1-10 ppt salinity, soft sediments, to all depths but most abundant in less than 10 meters.

Trophic Importance - *Leptocheirus plumulosus* is a mixed deposit/suspension feeder, ingesting detritus, algae, microorganisms, and some animal and vegetable debris. It inhabits a relatively shallow tube, in which it lies oriented ventral side uppermost. Food is collected by action of the setose appendages and transferred to the mouth.

L. plumulosus represents a major source of food for benthic feeding predators, particularly fish, because of its abundance and wide distribution. Holland *et al.* (1980) suggest that the temporal distribution of the species indicates that its standing stock is controlled by predation. It showed one of the largest increases in exclosure cages, and Holland *et al.* (1980) cite Hixon (1978, 1979) that the species is frequently observed as a food item of bottom feeding fish.

Like all tube-building species, *L. plumulosus* contributes to sediment stabilization, sorting, and oxygenation.

Selection Factors -

- Dominance in oligohaline and low mesohaline areas, and possibility of range reduction due to salinity increases.

- Importance as a food item to bottom-feeding predators.

Sources:

Boesch, unpubl.
Boesch *et al.*, 1976
Bousfield, 1972
Cory and Dresler, unpubl.
Diaz, 1977; pers. comm.
Ecological Analysts, 1974; 1979
Garety *et al.*, 1975*
Harman, unpubl.
Hixon, 1978; 1979
Holland *et al.*, 1979; 1980
Pfitzenmeyer, 1970; 1973; 1975
Pearson and Bender, 1975

* Reference not given in LFIS.

Palaemonetes pugio - Grass shrimp (Map 18)

Description - Palaemonetes pugio is a small (3 - 4 cm) decapod of the family Palaemonetidae. It is of typical shrimp form, transparent greenish-grey in color; the first two pairs of legs are chelate and longer than the six walking legs, the rostrum is long, laterally compressed, with stout spines. Females tend to be larger than males.

Range - Palaemonetes pugio is abundant in nearshore habitats along the Atlantic and Gulf coasts of North America. In many of these areas it occurs with its congeners P. vulgaris and P. intermedius, which has raised interesting questions as to habitat partitioning among these sympatric species. Palaemonetes typically inhabit areas which provide shelter, such as eel grass or other SAV beds, pilings, brush, cobbles, etc. and are less abundant along exposed shores. At high tide, they may enter marshes and feed upon detritus, algae, and small organisms.

In Chesapeake Bay, P. pugio is most abundant in oligohaline to polyhaline waters, although it has been found occasionally in tidal freshwater. In high mesohaline/polyhaline areas it co-occurs with P. vulgaris, the importance of which increases seaward.

P. pugio zoea are released into the plankton starting in early summer, and continue to be found until September. The larvae are most abundant in the bottom water layers where the net transport is upstream, and apparently utilize the characteristic two-layered estuarine circulation to retain themselves within the estuary.

Palaemonetes is abundant in its nearshore habitat until the coldest months, when it apparently retreats to deeper waters to overwinter.

Salinity Relationships - In Chesapeake Bay, P. pugio is found from 0 - 1 ppt to approximately 20 ppt salinity. P. vulgaris is of increasing importance above 15 ppt. At this point, the two species tend to occur in approximately equal numbers (Bowler and Seidenberg, 1971).

Because of the differences observed in the distributions of P. pugio ad P. vulgaris, numerous laboratory investigations have been made in an attempt to elucidate the habitat partitioning between the two species. In general, the larvae of both species appear to develop best at higher salinities; P. pugio larvae have an optimum range of 15 - 35 ppt with development significantly retarded below 10 ppt (Broad and Hubschman, 1962; Sandifer, 1973; McKenney and Neff, 1979). Some laboratory studies have shown adults of P. pugio to be tolerant of low salinities, with several investigators citing 3 ppt as the lethal lower limit for P. vulgaris (Nagabhushanam, 1961; Wood, 1967; Knowlton and Williams, 1970; Bowles and Seidenberg, 1971; Thorp and Hoss, 1975). However, the latter authors found that, above 3 ppt, both species were equally tolerant to salinity, and that salinity per se does not mediate habitat partitioning.

Welsh (1975) found P. pugio to be far more tolerant of low dissolved oxygen, high detritus, and poor circulation environments than is P. vulgaris, and that these are probably the major environmental variables affecting the two species distributions.

Other Sensitivities - *P. pugio* is also affected by temperature. Reproduction occurs when water temperatures warm in spring, with larvae released at about 18 - 20°C. Optimum survival and development occurs at 20 - 25°C. Juveniles are stressed at temperatures below 11°C, and survival is best at 18 - 25°C (Wood, 1967). The increase of proportion of *P. pugio* to *P. vulgaris* in high salinity areas in winter reported by Thorp and Hoss (1975) for Rhode Island may reflect downstream migration of the former species (as does *Crangon* in winter). *P. pugio* is restricted by availability of shelter, and has thus been affected by the recent bay-wide decline in SAVs.

Potential Habitat - Potential habitat for this species is defined as areas between 5 - 20 ppt salinity, where suitable cover exists; it is generallly found in less than 3 - 4 meters water.

Trophic Importance - *Palaemonetes pugio* is an important food organism for fish, particularly those species inhabiting nearshore areas (eg. *Fundulus*).

P. pugio is particularly important, however, as a detritivore and nutrient recycler (Welsh, 1975). The shrimp ingests detritus from marshes, as well as attached algae such as *Ulva* and diatoms, and assimilates the detritus and asociated bacteria. The mechanics of feeding also tend to "mill" or reduce the detritus particles size, enhancing decomposition. *P. pugio* thus represents a major pathway for transfer of energy and material from tidal marshes to higher trophic levels.

Selection Factors -

- Importance of estuarine circulation to maintenance of species within the estuary, and in transport of larvae from higher salinity areas where development is maximal to low salinity parts of range.

- Potential reduction of range downstream due to salinity increase.

Source -

Bowler and Seidenberg, 1971
Broad and Hubschman, 1962
Cargo, 1977
Knowlton and Williams, 1970
Lippson *et al.*, 1979
McKenney and Neff, 1979
Nagabhushana, 1961
Robblee, 1973
Sandifer, 1973; 1975
Thorp and Hoss, 1975
Welsh, 1975
Wood, 1967

Callinectes sapidus - Blue crab (Maps 19-22)

Description - Callinectes sapidus is a swimming crab of the family Portunidae. Adult crabs are 120 mm or larger across the body (point to point), and have the last pair of walking legs expanded and flattened for use in swimming. Males are typically larger than females, have larger claws, and a T-shaped abdominal apron, while that of the mature female is broadly rounded. The general body color is bluish-green or brownish-green, with a white underside, bright blue markings on the first pair of legs,and in the female, red tips on the claws. This is one of the most important commercial and recreational species in Chesapeake Bay.

Range - Blue crabs are found inshore from New England to Mexico, and have recently colonized the Mediterranean Sea (probably transported in ballast water). In Chesapeake Bay, they are found from freshwater to the Bay mouth, but there are distinct differences in the ranges of males and females. In summer, adult males range from freshwater into the polyhaline zone, with maximum concentrations from about 5 ppt to 20 ppt. Females are found in maximum numbers from 10 ppt to the Bay mouth, reflecting their orientation to the high salinity spawning areas. Where the two sexes overlap in abundance delineates the major areas of mating, which in the mainstem occupies Tangier Sound and the lower portion of the Maryland Bay. Mating occurs in summer, and is at a peak in August and early September. A male locates a suitable mate, "cradle-carries" her until she molts, and then mates while she is in the soft crab stage. After her shell hardens, she is released and begins her migration to the spawning grounds at the Bay mouth. Eggs may be released in late summer, or the sperm stored and used in the next year. Sponge crabs (females carrying eggs) are first seen in late May. Zoea are released in water over 23 ppt salinity in the lower Bay or on the shelf, usually nearshore. The zoea tend to be carried out of the Bay in surface waters. After metamorphosis to megalops, the young crab settles towards the bottom, and can be transported back into the Bay by bottom currents.

Newly metamorhosed true crabs being their up-Bay migration in about August, which (interrupted by winter) can continue until the next spring. Adult size is reached one to one and a half years after hatching.

In colder months, the crabs leave the shallow inshore areas, and seek greater depths than 10 - 15 meters. There they bury in the sediments to overwinter in a state of semihibernation. Most of the females are, by that time, in the lower Bay; this concentration of overwintering females supports a winter dredge fishery in Virginia.

Salinity Relationships - Physiologically, adult crabs can tolerate salinities from freshwater to oceanic levels (Tagatz, 1968). The observed differences in range of males and females reflects for the most part life history and breeding requirements. This spatial separation of the sexes apparently occurs at an early stage (Miller et al., 1975).

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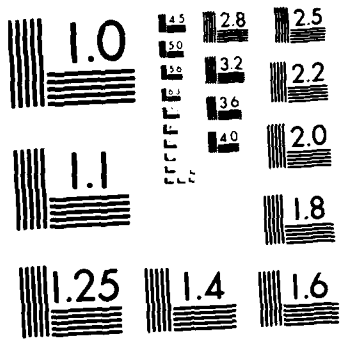

MICROCOPY RESOLUTION TEST CHART
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The spawning and development stages are, however, restricted by salinity. Spawning success is greatest and zoeal survival best at salinities between 23 - 30 ppt. If salinities are below about 18 ppt, eggs hatch in the abnormal "prezoea" stage, which dies. Optimal salinity range for development is about 21 - 28 ppt. The megalops is somewhat more tolerant of salinity, although the optimum range is between 20 - 35 ppt at 20 - 25 ^{o}C (Costlow, 1967). Higher salinities and lower temperatures delay metamorphosis to the crab stage, which has implications for the offshore transport of megalops between estuaries.

Other Sensitivities - Blue crabs are affected by temperature, both as adults and as larvae. The range of temperature necessary for hatching is 19 - 29^{o}C. Temperatures above 20^{o}C produce the most rapid development of the megalops; below this, development is delayed by a factor of 2 to 4 times.

Adult crabs are more active in warm water, and in fall as temperatures drop below 10^{o}C, they move to deeper water to overwinter. Lower temperatures affect the crab's ability to osmoregulate, and may prompt this migration (Amende, 1974).

Because of the blue crab's life history, maintenance of the species within the estuary depends upon the two-layered circulation pattern typical of Chesapeake Bay and on summer wind patterns. As the megalops metamorphose over the continental shelf, they migrate towards the bottom, and re-enter the Bay in bottom currents. The northward-flowing deep water assists the upestuary migration of the newly developed true crabs, as well. In addition, freshets tend to carry zoea out over the shelf, reducing the chance that the megalops will return into Chesapeake Bay (Van Engel, pers. comm.).

Potential Habitat - High density potential habitat in summer for males and juvenile females are areas from 5 to 20 ppt, while that of adult females is from 10 ppt to the Bay mouth. Spawning areas are nearshore waters where salinities exceed 23 ppt.

Trophic Importance - *Callinectes* is an active swimming and crawling scavenger and predator. The zoea prey upon zooplankton, and adults are major predators of benthic organisms. Crabs can dig and crack the shells of mollusks such as *Macoma*, *Mulinia*, *Mya*, *Rangia*, *Mercenaria*, and oyster spat and young oysters. They are important predators on numerous polychaete worms, as well, such as *Streblospio*, *Nereis*, and *Polydora* (Virnstein, 1979). Other food includes roots and stems of seaweeds and submerged aquatic vegetation, including *Zostera*, smaller crustacea, and fish (Van Engel, 1958; Tagatz, 1968).

The blue crab is itself used as food by a large number of species, including man. Many fish, such as the striped bass, feed upon young crabs, as do waterfowl and mammals such as raccoons. The species is one of the most important commercial and recreational organisms in Chesapeake Bay. About 50,000,000 pounds are harvested annually by commercal crabbers, and the sports fishery is probably equally large. Thus any effect on this species resulting from salinity change could have wide repercussions both environmentally and economically.

Selection Factors -

- Trophic importance, particularly as a predator on benthic invertebrates.

- Sensitivity of reproduction to salinity, circulation, and freshets.

- Major commercial and recreational importance.

Sources -

Amende, 1974
Costlow, 1967
Graham and Beaven, 1942
Holland et al., 1979; 1980
Lippson, 1971
Lippson et al., 1979
Miller et al., 1975
Pearson, 1948
Sandifer, 1973; 1975
Sandoz and Rogers, 1944
Tagatz, 1968
Van Engel, 1958; pers. comm.
Virnstein, 1977; 1979

Alosa sapidissima - American shad (Map 23)

Description - The shad is a member of the herring family, Clupeidae. The shad is the most sought after of the river herrings. Shad is an anadromous spawning marine fish. Color of the shad is dark blue to green on the back fading to silvery-white on the sides. The shad grows to 75 cm and is highly prized for its flavor and for the caviar-like shad roe.

Range - The shad enters coastal waters as they warm in the spring. Usually in March, when the water temperature in Chesapeake Bay has reached 13°C the fish begins its spawning run up the rivers. Where the rivers are not blocked by dams or other obstructions shad will move long distances upstream (formerly as far as 480 km up the Susquehanna). Most spawning currently is located much closer to the salt water interface due to the prevalence of stream obstructions. Spawning occurs in rapidly flowing water over clean sand or gravel bottom. Eggs are nonadhesive and rolled along with the current. In larger rivers spawning tends to occur in the channels. Eggs hatch in two weeks at 11°C. Juvenile shad remain in the river until fall at which time (around October) they leave for the ocean. Adults return to sea after spawning. They have generally left the bay by the end of June.

Salinity Relationships -

- Eggs - freshwater <5 ppt.
- Larvae - freshwater to oligohaline <5 ppt.
- Juveniles - oligohaline region into low mesohaline <12 ppt gradually moving into more saline regions.
- Adults - freshwater to euhaline (oceanic).

Low Flow Sensitivities - A. sapidissima require flowing freshwater with dissolved oxygen levels above 5 ppm and clean sand or gravel bottoms. High temperatures, above 21°C, and low D.O. have proved to be a barrier to the downstream migration of juveniles. Physical barriers to spawning migrations are sufficiently prevalent even on minor tributaries that the population has suffered severe decline. Intrusion of salt into the remaining spawning reaches below dams and barricades may be sufficient to eliminate entire year classes.

Potential Habitat - This species is mapped for the juvenile life stage, which is found at salinities from 1 to 12 ppt.

Trophic Importance - Adult shad feed mainly on copepods in the surface layer. Other small fish and planktonic crustaceans form a small part of the diet. The trophic impact of shad on Chesapeake Bay is limited by the pattern of not eating during migration and prompt return to the ocean after spawning by the adults. Juvenile shad are planktivores and form an important prey resource for top predators.

Selection Factors - Offshore overfishing, water quality problems in spawning rivers and greatly restricted access to spawning habitat have contributed to a drastic population decline in the Chesapeake Bay. Additional restrictions of spawning habitat due to upstream displacement of salinity is likely to produce an immediate and abrupt result.

Sources:

Annon, 1968
Carter, 1980
Dovel, 1971
VEPCO, 1976
Hildebrand and Schroeder, 1928
Johnson *et al.*, 1978
Jones *et al.*, 1978
Kriete, W., pers. comm.
Lippson and Moran, 1974
Lippson *et al.*, 1979
Neves and Depres, 1979
Raney and Massman, 1953
Scott and Boone, 1973
Wang and Kernehan, 1979
Whitney, 1961

Brevoortia tyrannus - Atlantic menhaden (Map 24)

Description - The menhaden is a member of the herring family, Clupeidae. The adult menhaden is a marine spawner which is dependent on the estuary both as a nursery for juveniles and as a feeding ground during the summer months. The adult fish is a dark blue to green with a conspicuous dark spot behind the head. Menhaden grow to a length of 46 cm and is the single most important non-food fish on the East or Gulf Coast.

Range - Menhaden enter Chesapeake Bay from the ocean in April and remain until October. Post-larval menhaden enter the Bay during the winter or early spring from spawning areas on the continental shelf. Post-larvae accumulate at the fresh/salt water interface. After metamorphosis the juveniles begin to move from the fresh water interface through the oligohaline zone into the mesohaline zone. Larger fish are found in deeper water and further down the Bay. After metamorphosis the fish become pelagic feeders. Sub-adults will leave the estuary with the adults in October.

Salinity Relationships -

- Eggs - oceanic
- Larvae - oceanic drifting to tidal fresh on the bottom current.
- Juveniles - moving generally in surface layer from oligohaline to euhaline (oceanic).
- Adults - wandering from mesohaline (5 ppt) to euhaline with areas of concentrated adults and juveniles (5-8 ppt) following plankton patches.

Low Flow Sensitivities - Change in stratification and net upstream drift of bottom waters could change delivery of larvae to low salinity nursery area. Breakdown of stratification could disperse plankton concentrations and make feeding more difficult for adults.

Potential Habitat - Nursery area is the only critical habitat, potential nursery area described by salinity within the 0 ppt to 5 ppt zone, shallow waters, with organic bottom sediments and high plankton productivity.

Trophic Importance - The only forage fish feeding directly on primary producers, menhaden are a major energy pathway from plankton direct to large piscivores. Present in exceedingly dense aggregations, the filter feeding of menhaden is a primary limit to plankton abundances.

Selection Factors -

- Unique trophic importance.
- Dependence on estuarine circulation for reproduction.
- Dependence on high primary productivity of turbidity maximum.

Sources

Beauchamp, 1974
Colton et al., 1979
Dovel, 1971
Durbin, 1976
Harrison et al., 1967
Hildebrand and Schroeder, 1928
Jones et al., 1978
Jordon et al., 1976; 1977; 1978
Lewis, 1966
Lippson et al., 1979
Massmann et al., 1962
McHugh et al., 1959
Olney, 1978
Oviatt et al., 1972
Ritchie and Koo, 1973
Scott and Boone, 1973
Wang and Kernehan, 1979
Weinstein, 1979

Anchoa mitchilli - Bay anchovy (Map 25)

Description - The bay anchovy is a delicate, soft bodied small fish with large eyes and an underslung jaw giving it a "chinless" profile. The bay anchovy belongs to the family Engraulidae. The bay anchovy grows to a length of 10 cm and is translucent with a narrow horizontal silvery strips along each side. The bay anchovy is more inshore and estuarine oriented than is Anchoa hepsetus with which it competes in the higher salinity regions.

Range - The bay anchovy is found in open water throughout the Bay from the freshwater zone to the euhaline zone. The Low Freshwater Inflow Study states that the bay anchovy spawns in the lower oligohaline/upper mesohaline zone and also utilizes this area as a nursery zone. However, studies from the lower Chesapeake Bay indicate most of he lower Bay is also an important nursery area (Olney, 1978; Ecological Analysts, 1979). Larvae and juveniles are pelagic, shoreward oriented and euryhaline. Juveniles have been recorded far upstream of the limit of tidal influence in Virginia rivers. The juveniles are most abundant at the salt-freshwater front.

Salinity Relationships -

- eggs - 5-15 ppt
- larvae - 8-26 ppt
- juveniles - 0-35 ppt
- adults - 0-35 ppt

Low Flow Sensitivities - The most sensitive life stage appears to be that of the larvae which collect in the surface waters of the oligohaline salinity zone. Movement of the oligohaline region into narrower regions of the tributary estuaries will concentrate the larvae and reduce the area available for feeding and growth. Larvae and early juveniles are dependent on the density of copepod nauplii for food. Crowding may well result in food limitation and reduction in size of year class of these important forage fish.

Potential Habitat - Potential spawning habitat is open water with a salinity between 5 and 15 ppt. Potential habitat of larvae is the shallow shore zone where the salinity is between 8 and 26 ppt, while the adult's habitat is all open water from tidal fresh to the ocean (euhaline zone).

Trophic Importance - Young anchovies feed exclusively on copepods. They may compete with alosid larvae for copepods, where ranges overlap. Adult anchovies feed upon copepods and other planktonic crustaceans such as crab larvae, mysids and cladocerans. In some areas larval fish are also taken by adult anchovies, however this does not occupy a substantial portion of their diet. In turn, the bay anchovy is fed on quite heavily by white perch and yellow perch, young bluefish and young striped bass. Juvenile weakfish are particularly dependent on anchovies for forage. In addition to its high abundance, the anchovy is important as a forage fish becauuse of its presence in the Bay year round.

Selection Factors - The sensitivity of the larval stage to salinity, the importance of the anchovy as a forage fish, and its high biomass and wide distribution are all factors which contributed to the selection of the Bay anchovy as a study species.

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Morone saxatilis - Striped bass (Map 26)

Description - The striped bass is a close relative of the white perch. A member of the family Percicthyidae, the striped bass is an anadromous marine fish which can grow as large as 127 cm. The fish is olive green shading to white on the ventral surface with seven dark horizontal stripes which gives the species its common name. It is highly prized as a sport fish and is also netted commercially in Chesapeake Bay. The Chesapeake historically provided in excess of 80% of the Atlantic coastal striped bass stock prior to its recent severe decline.

Range - Within Chesapeake Bay the striped bass is found from the ocean to the fall line. Formerly striped bass ascended far up the Susquehanna River but the route is presently blocked by dams. The Chesapeake and Delaware Canal is used both for migration to and from Chesapeake Bay and as a major spawning area. Younger fish tend to be found in shallower and less saline water. During summer the striped bass is oriented to high energy shorelines (rocky points, beaches, and hard bottom where there is a current). During the winter striped bass seek out deep holes and channels where they remain relatively inactive. Larger fish are found in the high mesohaline to low polyhaline regions along the bottom. Younger fish may be found further upstream in winter, also in deep water.

Salinity Relationships -

- eggs - tidal fresh to 1 ppt
- larvae - tidal fresh to oligohaline
- juveniles - tidal fresh to mesohaline
- adults - spawning migrations to freshwater, otherwise mid-mesohaline to euhaline.

Low Fow Sensitivities - Spawning requires turbulent water to keep the eggs in suspension. Spawning is apparently successful only in turbulent silty areas of rocky or hard bottoms and only in fresh water. Some studies have indicated that fish will not enter a river during periods of low discharge from upstream dams. This will be one of the anticipated effects of the regularizing of the river flow resulting from the construction of additional impoundments.

Potential Habitat - Potential habitat for juvenile striped bass is shallow areas with salinities between 0 and 10 ppt.

Trophic Importance - Striped bass are large active predators feeding on a wide variety of fish and crustaceans. Larval striped bass are dependent upon the densities of copepod nauplii and other very small planktonic crustaceans. As the striped bass grow, their size of prey increases also. Large striped bass have been accused of making severe inroads on populations of juvenile Atlantic croaker over the winter. The most significant predator on adult striped bass is man. The sport fish landings may exceed the commercial fisheries landings by approximately a factor of two.

Selection Factors - The large number of studies on the biology and distribution of the striped bass, the sensitivity of its egg and larval stages to the circulation and salinity changes and high trophic importance were all contributing factors in the selection of the striped bass as a study species. In addition, the fish has a high economic and social importance which, interacting with concern about the decline in population make this study species of considerable interest.

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APPENDIX B

AVERAGE SEASONAL SALINITIES

FROM THE

CORPS OF ENGINEERS

HYDRAULIC MODEL TEST

Table B-1. Average spring salinities, base and plan conditions.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt) Surface	Base Condition Salinity (ppt) Bottom	Plan Condition Salinity (ppt) Surface	Plan Condition Salinity (ppt) Bottom
AC0002	50*	24.39	32.48	24.28	32.43
AC0003	50*	24.29	32.37	23.50	32.30
BG0101	10	17.13	17.18	17.01	17.07
CB0001	33	24.90	31.64	24.84	31.84
CB0002	68	23.06	32.33	22.94	32.28
CB0003	32	24.82	32.14	24.68	31.92
CB0004	30	25.57	31.40	23.41	31.49
CB0005	17	26.82	30.99	24.99	30.91
CB0006	12	24.80	28.92	24.30	28.95
CB0007	18	27.03	31.12	26.58	30.83
CB0008	43	26.06	30.86	25.50	30.27
CB0009	16	26.55	29.38	26.08	28.90
CB0101	15	18.10	19.56	17.94	19.63
CB0102	18	18.62	21.14	18.17	21.18
CB0103	28	18.51	24.86	18.31	25.48
CB0104	30	18.39	26.85	17.94	27.13
CB0105	37	18.70	28.17	18.36	28.57
CB0106	22	19.03	26.13	18.74	26.82
CB0107	27	18.68	25.72	18.59	26.01
CB0108	28	18.31	23.86	18.04	23.97
CB0109	72	17.66	28.12	17.54	28.40
CB0110	17	17.73	22.10	17.77	21.84
CC0001	52	24.82	32.14	24.38	32.06
CC0002	47	24.97	31.87	24.70	32.17
CO0101	20	0.13	0.11	0.14	0.07
CO0201	10	0.11	0.10	0.07	0.07
EE0101	28	16.55	24.87	16.76	26.37
EE0201	24	16.75	23.55	16.85	24.56
EE0301	24	16.79	21.34	17.19	22.73
EH0101	12	18.36	19.69	19.02	21.17
EH0102	48*	18.31	26.84	19.63	29.18
EH0103	14	18.73	20.84	19.26	21.48
EH0201	4	16.83	16.83	16.75	16.75
EH0202	48*	17.01	27.39	17.68	29.00
EH0203	43	16.66	25.25	17.41	26.96
EH0301	48	17.30	27.83	17.03	27.61
EH0302	24	17.22	22.12	16.98	22.77
EH0401	44*	17.09	27.36	17.26	28.90
EH0501	42*	17.04	26.88	17.35	28.89

* Denotes station where depth will increase under plan condition.

Table B-1. Average spring salinities, Cont'd.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt) Surface	Bottom	Plan Condition Salinity (ppt) Surface	Bottom
EH0601	42*	17.56	27.36	17.81	28.70
EH0701	36*	17.24	26.77	18.35	28.47
EH0801	36*	16.87	26.58	18.03	27.83
EH0901	36	12.41	26.18	13.57	27.34
EH1001	13	13.08	18.97	14.08	19.60
JG0101	13	19.96	21.12	19.23	21.70
JG0102	43	19.12	25.93	19.02	26.90
JG0103	72	20.23	28.72	19.14	29.46
JG0211	14	16.97	17.85	16.92	17.92
JG0201	12	17.26	18.71	16.96	18.84
JG0202	22	18.26	21.16	18.41	21.80
JG0203	43	18.24	23.07	18.66	23.95
JG0311	14	8.92	11.07	9.14	11.68
JG0301	18	9.08	11.93	9.11	12.36
JG0302	30	11.06	13.78	11.61	14.83
JG0321	4	11.34	11.34	11.54	11.54
JG0401	19	2.51	3.04	2.65	3.30
JG0402	28	2.35	3.28	2.60	3.84
JG0501	20	0.75	0.91	0.79	1.01
JG0502	39	0.89	1.10	0.91	1.14
JG0601	23	0.10	0.07	0.10	0.06
JG0701	29	0.08	0.05	0.17	0.08
JG0801	25	0.14	0.07	0.15	0.11
JG0901	29	0.10	0.07	0.05	0.05
JG1001	24	0.08	0.06	0.06	0.03
JN0101	20	19.88	23.21	19.24	23.59
JN0102	44*	19.98	26.15	19.58	25.77
JN0103	58	19.59	26.53	19.07	26.99
JN0104	44	19.92	26.48	19.61	26.91
JN0105	12	19.33	19.75	19.14	19.82
JN0201	12	17.23	18.24	17.37	18.68
JN0202	14	17.94	19.24	18.24	19.84
JN0203	23	18.47	20.82	18.97	21.14
JN0204	50*	18.47	25.25	18.28	26.62
JN0205	22	18.19	21.18	17.07	21.67
JN0301	4	12.63	12.63	12.46	12.46
JN0302	18	13.97	14.77	14.44	15.59
JN0303	32	13.77	18.88	14.28	19.83
JN0304	4	11.47	11.47	12.08	12.08
JN0401	24	5.66	6.38	5.87	6.96
JN0501	14	4.37	5.06	4.68	5.39
JN0502	31	4.94	7.67	5.17	8.69

Table B-1. Average spring salinities, Cont'd.

Station	Base Condition (ft. below msl)*	Base Condition Salinity (ppt)		Plan Condition Salinity (ppt)	
		Surface	Bottom	Surface	Bottom
JN0601	10	2.19	2.27	2.27	2.35
JN0602	10	1.89	1.94	2.06	2.01
JN0603	28	1.53	1.76	1.61	2.03
JN0701	4	1.67	1.67	1.66	1.66
JN0801	25	0.25	0.32	0.38	0.40
JN0802	12	0.16	0.14	0.24	0.24
JN0803	24	0.26	0.27	0.20	0.16
LF0101	4	18.20	18.20	18.11	18.11
LF0201	16	16.69	17.24	16.10	16.96
LF0301	10	16.56	16.25	16.30	17.40
LH0001	20	22.73	29.96	22.31	30.13
LS0001	18	20.46	23.73	19.79	24.09
LS0002	23	21.21	27.23	20.83	26.66
LS0003	24	20.96	28.98	20.36	28.43
LS0004	18	21.45	27.59	20.83	27.29
MB0102	20	16.58	19.18	15.92	19.38
NN0001	50*	20.04	26.48	17.37	18.68
NS0101	17	16.19	17.39	16.22	17.85
NS0102	4	16.44	16.44	16.35	16.35
NS0201	20	15.23	15.62	15.38	15.87
NS0301	19	14.21	14.60	14.59	15.18
NS0401	10	13.71	14.24	13.47	13.45
NS0501	4	10.61	10.61	10.45	10.45
PQ0101	10	16.77	17.51	16.85	17.72
RS0003	52	15.20	26.24	14.90	27.04
TS0001	49	24.01	32.03	23.79	32.04
TS0002	49*	23.55	31.79	23.82	31.88
TS0003	49*	23.24	31.56	23.26	31.96
TS0004	49*	20.93	30.96	20.89	31.51
TS0005	49*	20.22	30.89	20.21	31.37
WB0101	14	17.60	19.74	17.46	20.20
WB0201	16	16.75	17.92	14.43	18.55
WO0101	10	19.37	20.74	19.80	21.37
YG0101	34	17.02	23.26	16.82	23.90
YG0102	54	17.55	27.23	17.38	27.98
YG0201	59	18.20	26.42	17.80	26.71
YS0001	49	21.98	30.90	21.46	30.65
YS0002	49	19.63	29.51	19.55	29.86
YS0003	49	19.17	28.13	18.24	28.33
YS0004	49	16.43	27.55	17.12	28.24
YS0005	52	17.68	28.34	17.62	28.76
SAO	60	23.54	31.97	23.67	31.93
SBO	30	20.77	27.18	20.94	27.50

Table B-2. Average summer salinities, base and plan conditions.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt) Surface	Base Condition Salinity (ppt) Bottom	Plan Condition Salinity (ppt) Surface	Plan Condition Salinity (ppt) Bottom
AC0002	50*	27.24	32.37	27.89	32.39
AC0003	50*	26.73	32.37	26.69	32.41
BG0101	10	19.56	19.76	19.73	19.83
CB0001	33	27.04	31.44	27.33	31.84
CB0002	68	25.42	32.21	25.38	32.21
CB0003	32	27.52	31.95	27.19	31.77
CB0004	30	27.39	31.49	27.66	31.38
CB0005	17	27.64	30.94	27.33	31.25
CB0006	12	27.70	30.11	27.44	30.28
CB0007	18	29.16	31.30	29.26	31.70
CB0008	43	28.67	31.11	28.58	31.17
CB0009	16	28.83	30.21	28.59	30.19
CB0101	15	20.61	22.18	20.49	22.52
CB0102	18	21.14	23.48	21.02	23.74
CB0103	28	21.19	25.65	21.36	26.39
CB0104	30	21.18	27.25	21.01	27.61
CB0105	37	21.44	28.21	21.45	28.92
CB0106	22	21.53	27.57	21.69	28.23
CB0107	27	21.53	26.92	21.62	27.64
CB0108	28	21.15	25.97	21.01	26.12
CB0109	72	20.55	28.24	20.73	28.63
CB0110	17	20.81	24.44	20.81	24.68
CC0001	52	27.17	32.14	27.20	32.01
CC0002	47	27.33	31.95	27.18	31.89
CO0101	20	1.11	1.20	1.22	1.26
CO0201	10	0.84	0.85	0.89	0.88
EE0101	28	21.60	25.05	22.06	26.47
EE0201	24	22.02	24.37	22.64	25.60
EE0301	24	21.81	22.72	22.33	23.60
EH0101	12	22.59	23.03	22.59	23.81
EH0102	48*	22.49	27.05	23.51	29.06
EH0103	14	22.41	23.29	23.03	24.14
EH0201	4	21.83	21.83	22.39	22.39
EH0202	48*	21.90	27.33	22.27	27.73
EH0203	43	21.85	26.26	22.43	27.00
EH0301	48	21.90	27.34	22.54	27.95
EH0302	24	21.69	23.74	22.52	24.35
EH0401	44*	21.94	27.52	22.21	28.59
EH0501	42*	21.77	27.14	22.41	28.62

* Denotes station where depth will increase under plan condition.

Table B-2. Average summer salinities, Cont'd.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt) Surface	Bottom	Plan Condition Salinity (pp.) Surface	Bottom
EH0601	42*	21.89	27.11	22.84	28.44
EH0701	36*	21.68	26.38	22.71	28.11
EH0801	36*	21.80	26.22	23.12	27.70
EH0901	36	19.74	25.74	21.03	27.33
EH1001	13	20.00	22.23	21.31	23.12
JG0101	13	23.08	23.37	23.26	24.11
JG0102	43	22.03	26.05	22.40	27.19
JG0103	72	22.37	28.81	22.33	29.76
JG0211	14	21.31	21.76	22.42	22.74
JG0201	12	21.54	22.07	21.23	22.39
JG0202	22	22.37	23.03	23.33	23.65
JG0203	43	22.30	24.58	23.00	25.47
JG0311	14	14.37	15.75	15.08	16.47
JG0301	18	14.53	15.91	15.26	16.45
JG0302	30	16.33	16.96	17.32	17.89
JG0321	4	14.72	14.72	15.18	15.18
JG0401	19	7.44	8.43	8.09	9.15
JG0402	28	7.54	8.81	8.05	9.59
JG0501	20	3.95	4.74	4.60	5.29
JG0502	39	4.33	5.10	4.78	5.63
JG0601	23	1.09	1.39	1.31	1.75
JG0701	29	0.24	0.16	0.36	0.19
JG0801	25	0.09	0.07	0.19	0.11
JG0901	29	0.06	0.04	0.09	0.06
JG1001	24	0.11	0.08	0.02	0.00
JN0101	20	23.62	25.26	23.52	25.71
JN0102	44*	22.97	26.30	23.51	27.13
JN0103	58	22.81	26.83	22.62	27.15
JN0104	44	22.97	26.71	23.07	27.27
JN0105	12	23.28	23.46	23.49	23.67
JN0201	12	21.47	21.84	22.33	22.56
JN0202	14	22.20	22.58	22.92	23.30
JN0203	23	22.80	23.74	23.52	24.12
JN0204	50*	23.09	26.21	23.46	26.82
JN0205	22	22.88	23.85	22.93	24.28
JN0301	4	18.23	18.23	18.75	18.75
JN0302	18	18.70	19.02	19.51	19.71
JN0303	32	18.61	21.02	19.74	21.89
JN0304	4	17.37	17.37	17.81	17.81
JN0401	24	11.26	11.83	12.04	12.79
JN0501	14	10.07	10.91	10.60	11.47
JN0502	31	10.62	12.38	11.12	13.16

Table B-2. Average summer salinities, Cont'd.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt) Surface	Base Condition Salinity (ppt) Bottom	Plan Condition Salinity (ppt) Surface	Plan Condition Salinity (ppt) Bottom
JN0601	10	6.89	7.08	7.55	7.61
JN0602	10	6.66	6.72	7.29	7.26
JN0603	28	6.29	6.93	6.42	7.41
JN0701	4	5.90	5.90	6.35	6.35
JN0801	25	2.51	2.97	2.72	3.15
JN0802	12	2.18	2.39	2.23	2.32
JN0803	24	1.49	1.75	1.56	1.81
LF0101	4	22.91	22.91	23.09	23.09
LF0201	16	22.03	22.13	22.25	22.63
LF0301	10	21.69	22.10	21.96	22.23
LH0001	20	24.86	29.58	25.90	30.01
LS0001	18	23.13	25.31	23.38	26.21
LS0002	23	23.68	27.18	23.91	27.24
LS0003	24	23.38	28.83	23.64	28.65
LS0004	18	23.73	28.03	23.72	28.25
MB0102	20	18.46	21.26	18.58	21.80
NN0001	50*	23.49	26.40	24.06	26.63
NS0101	17	20.92	21.26	22.02	22.37
NS0102	4	21.17	21.17	22.07	22.07
NS0201	20	20.49	20.59	21.11	21.33
NS0301	19	20.19	20.44	20.71	21.02
NS0401	10	19.30	19.42	19.97	20.06
NS0501	4	17.49	17.49	18.43	18.43
PQ0101	10	19.32	20.00	19.36	20.17
RS0003	52	18.18	26.26	18.25	26.74
TS0001	49	26.35	32.04	26.24	31.92
TS0002	49*	25.98	31.85	27.29	31.96
TS0003	49*	25.34	31.59	25.80	31.82
TS0004	49*	23.52	31.24	23.61	31.41
TS0005	49*	22.95	30.94	23.23	31.21
WB0101	14	21.77	22.74	22.70	23.96
WB0201	16	21.51	21.77	23.39	22.63
WO0101	10	22.91	23.32	23.56	24.06
YG0101	34	19.56	24.26	19.85	25.02
YG0102	54	19.91	26.53	20.57	27.40
YG0201	59	21.13	25.87	21.09	26.57
YS0001	49	24.18	30.66	24.27	30.73
YS0002	49	22.97	29.40	22.65	29.82
YS0003	49	20.97	28.09	21.13	28.43
YS0004	49	19.86	27.97	19.99	28.68
YS0005	52	19.89	28.74	20.60	28.78
SAO	60	26.19	32.04	26.34	32.18
SBO	30	23.39	28.05	23.62	28.49

Table B-3. Average fall salinities, base and plan conditions.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt) Surface	Base Condition Salinity (ppt) Bottom	Plan Condition Salinity (ppt) Surface	Plan Condition Salinity (ppt) Bottom
AC0002	50*	29.45	32.45	29.59	32.40
AC0003	50*	29.04	32.37	29.23	32.45
BG0101	10	22.85	22.94	23.23	23.30
CB0001	33	28.47	31.60	28.84	31.62
CB0002	68	28.47	32.30	28.38	32.35
CB0003	32	28.88	32.34	28.93	32.18
CB0004	30	28.81	31.52	28.61	31.45
CB0005	17	29.73	31.26	29.37	31.18
CB0006	12	30.15	31.20	30.03	31.21
CB0007	18	31.11	31.60	31.02	31.54
CB0008	43	31.10	31.72	30.84	31.49
CB0009	16	30.85	31.38	30.80	31.16
CB0101	15	23.02	23.72	23.72	24.49
CB0102	18	24.22	25.66	24.56	25.58
CB0103	28	24.74	27.09	24.45	26.98
CB0104	30	24.48	27.96	24.32	27.88
CB0105	37	24.69	28.88	24.55	28.68
CB0106	22	25.26	28.49	25.03	28.32
CB0107	27	25.10	28.38	25.19	28.50
CB0108	28	24.27	27.95	24.18	27.62
CB0109	72	23.75	29.32	23.90	29.24
CB0110	17	24.03	26.29	24.27	26.31
CC0001	52	29.21	32.33	29.04	32.08
CC0002	47	28.77	31.99	28.88	32.08
CO0101	20	3.16	3.22	3.08	3.16
CO0201	10	2.79	2.82	2.70	2.76
EE0101	28	23.81	25.24	24.26	26.04
EE0201	24	24.14	24.98	24.50	25.65
EE0301	24	24.13	24.78	24.47	25.09
EH0101	12	24.07	24.65	24.72	25.30
EH0102	48*	24.33	27.20	24.88	28.55
EH0103	14	24.35	24.87	24.88	25.43
EH0201	4	23.95	23.95	24.30	24.30
EH0202	48*	23.75	27.06	24.43	28.93
EH0203	43	23.42	26.56	24.21	27.22
EH0301	48	23.84	27.15	24.33	28.12
EH0302	24	23.80	25.03	23.83	25.38
EH0401	44*	23.80	27.34	24.42	28.60
EH0501	42*	24.08	27.05	24.49	28.31

* Denotes station where depth will increase under plan condition.

Table B-3. Average fall salinities, Cont'd.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt) Surface	Base Condition Salinity (ppt) Bottom	Plan Condition Salinity (ppt) Surface	Plan Condition Salinity (ppt) Bottom
EH0601	42*	24.06	27.09	24.73	28.31
EH0701	36*	24.14	26.34	24.84	27.78
EH0801	36*	23.47	25.96	24.66	27.54
EH0901	36	21.72	25.52	22.53	27.03
EH1001	13	21.16	24.64	22.16	24.97
JG0101	13	24.95	25.11	25.47	25.58
JG0102	43	24.45	26.65	24.53	27.15
JG0103	72	24.75	28.27	24.32	29.53
JG0211	14	23.42	23.69	22.71	23.09
JG0201	12	23.01	23.68	23.45	24.19
JG0202	22	23.81	24.55	24.52	24.99
JG0203	43	24.10	25.30	24.03	25.88
JG0311	14	16.61	17.69	16.70	17.73
JG0301	18	16.62	17.58	16.99	17.86
JG0302	30	18.00	18.67	18.27	18.94
JG0321	4	15.92	15.92	16.35	16.35
JG0401	19	9.37	10.69	9.88	10.89
JG0402	28	9.83	10.83	9.85	11.28
JG0501	20	6.04	6.87	5.99	7.09
JG0502	39	6.43	7.29	6.48	7.44
JG0601	23	2.65	3.50	2.55	3.57
JG0701	29	0.72	1.15	1.12	1.30
JG0801	25	0.29	0.34	0.31	0.35
JG0901	29	0.12	0.07	0.21	0.12
JG1001	24	0.08	0.09	0.26	0.05
JN0101	20	25.20	26.27	25.14	26.77
JN0102	44*	24.75	26.81	25.05	27.79
JN0103	58	24.91	27.25	24.79	27.32
JN0104	44	24.84	27.23	25.03	27.23
JN0105	12	25.14	25.18	25.18	25.37
JN0201	12	23.57	23.79	23.63	23.84
JN0202	14	23.97	24.12	24.06	24.43
JN0203	23	24.68	25.08	24.75	25.49
JN0204	50*	24.70	26.45	24.80	27.11
JN0205	22	24.58	25.51	24.08	25.69
JN0301	4	20.58	20.58	20.40	20.40
JN0302	18	20.73	20.98	20.82	20.91
JN0303	32	20.61	22.81	21.06	22.97
JN0304	4	19.18	19.18	19.36	19.36
JN0401	24	13.44	13.86	13.82	14.25
JN0501	14	12.50	13.10	12.51	13.08
JN0502	31	12.87	13.94	12.98	14.47

Table B-3. Average fall salinities, Cont'd.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt)		Plan Condition Salinity (ppt)	
		Surface	Bottom	Surface	Bottom
JN0601	10	9.19	9.40	9.38	9.45
JN0602	10	8.96	8.93	9.30	9.20
JN0603	28	8.53	9.06	8.68	9.17
JN0701	4	8.42	8.42	8.40	8.40
JN0801	25	4.34	5.07	4.32	5.07
JN0802	12	4.09	4.17	4.00	4.18
JN0803	24	3.00	3.28	3.40	3.66
LF0101	4	24.47	24.47	24.70	24.70
LF0201	16	23.97	24.20	24.27	24.46
LF0301	10	23.89	24.16	24.14	24.68
LH0001	20	27.81	29.95	27.83	29.78
LS0001	18	26.28	26.95	26.17	26.82
LS0002	23	26.45	27.62	26.35	27.24
LS0003	24	26.25	28.99	26.24	28.68
LS0004	18	26.63	28.46	26.42	28.04
MB0102	20	21.68	23.71	22.10	24.15
NN0001	50*	25.04	27.05	25.39	27.18
NS0101	17	23.07	23.22	23.34	23.72
NS0102	4	23.15	23.15	23.57	23.57
NS0201	20	22.38	22.59	22.74	26.96
NS0301	19	21.91	23.18	22.42	22.80
NS0401	10	21.43	21.64	21.96	22.08
NS0501	4	19.57	19.57	20.02	20.02
PQ0101	10	21.19	22.65	22.64	23.08
RS0003	52	21.13	26.13	21.35	26.51
TS0001	49	29.32	31.99	28.92	31.96
TS0002	49*	29.04	32.20	29.53	31.89
TS0003	49*	27.66	31.69	27.61	31.69
TS0004	49*	26.14	30.88	26.60	31.41
TS0005	49*	25.58	30.75	25.86	31.26
WB0101	14	24.42	24.89	24.59	25.06
WB0201	16	24.45	24.68	24.37	24.58
WO0101	10	24.97	25.36	25.23	25.59
YG0101	34	22.98	24.98	23.28	25.07
YG0102	54	23.23	26.15	23.47	26.46
YG0201	59	23.36	25.42	23.53	25.91
YS0001	49	27.00	30.35	27.25	30.45
YS0002	49	26.44	29.87	26.02	29.57
YS0003	49	24.94	28.35	24.60	28.50
YS0004	49	22.94	27.95	23.68	28.65
YS0005	52	23.32	29.02	23.58	28.65
SA0	60	29.16	32.02	29.07	32.20
SB0	30	26.40	28.71	26.72	28.99

Table B-4. Average winter salinities, base and plan conditions.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt) Surface	Base Condition Salinity (ppt) Bottom	Plan Condition Salinity (ppt) Surface	Plan Condition Salinity (ppt) Bottom
AC0002	50*	27.61	32.49	27.50	32.44
AC0003	50*	27.30	32.40	26.72	32.23
BG0101	10	21.55	21.75	21.54	21.41
CB0001	33	27.34	31.83	27.33	31.65
CB0002	68	26.00	32.27	25.38	32.35
CB0003	32	27.90	32.32	26.87	31.98
CB0004	30	27.31	31.41	27.47	31.36
CB0005	17	28.71	30.90	27.75	30.79
CB0006	12	27.83	29.80	28.16	29.82
CB0007	18	29.61	31.25	29.35	30.95
CB0008	43	29.93	31.63	29.41	30.71
CB0009	16	29.80	30.79	29.46	30.15
CB0101	15	22.03	23.52	21.80	22.96
CB0102	18	23.22	24.70	22.75	23.99
CB0103	28	23.25	25.59	22.90	25.84
CB0104	30	23.11	26.54	23.05	27.35
CB0105	37	23.69	28.45	23.27	28.17
CB0106	22	23.72	26.95	23.69	27.14
CB0107	27	23.75	27.07	23.98	26.94
CB0108	28	23.19	26.21	23.28	26.01
CB0109	72	22.36	27.99	22.79	28.33
CB0110	17	22.94	24.79	23.19	24.64
CC0001	52	27.48	32.32	26.99	31.80
CC0002	47	27.20	31.85	27.27	32.18
CO0101	20	0.44	0.49	0.28	0.29
CO0201	10	0.39	0.29	0.23	0.28
EE0101	28	16.61	25.29	15.10	26.01
EE0201	24	16.26	24.36	15.65	24.78
EE0301	24	16.55	24.51	15.98	24.86
EH0101	12	17.97	20.95	17.43	22.26
EH0102	48*	18.26	26.86	19.05	28.75
EH0103	14	18.50	22.59	18.53	22.95
EH0201	4	15.58	15.58	15.74	15.74
EH0202	48*	16.14	26.91	17.22	28.93
EH0203	43	16.71	26.39	16.52	26.62
EH0301	48	16.72	27.53	16.07	28.02
EH0302	24	16.50	23.53	16.23	23.69
EH0401	44*	16.59	27.83	16.27	28.73
EH0501	42*	17.03	27.24	16.44	28.46

* Denotes station where depth will increase under plan condition.

Table B-4. Average winter salinities, Cont'd.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt) Surface	Bottom	Plan Condition Salinity (ppt) Surface	Bottom
EH0601	42*	17.05	27.30	17.64	28.39
EH0701	36*	17.20	26.40	18.54	27.98
EH0801	36*	15.05	26.18	16.24	27.86
EH0901	36	8.47	25.90	6.72	27.19
EH1001	13	7.90	20.44	7.53	20.88
JG0101	13	19.74	22.58	19.62	23.14
JG0102	43	19.48	25.86	19.92	26.72
JG0103	72	21.10	28.14	20.87	29.25
JG0211	14	16.03	17.70	16.20	17.84
JG0201	12	16.27	18.91	15.57	18.66
JG0202	22	17.64	22.33	17.31	22.63
JG0203	43	17.90	23.54	17.36	24.03
JG0311	14	6.97	9.61	6.76	9.70
JG0301	18	6.94	10.55	6.74	11.20
JG0302	30	8.88	12.90	8.56	13.59
JG0321	4	10.72	10.72	10.83	10.83
JG0401	19	2.17	2.42	2.08	2.34
JG0402	28	2.03	2.34	1.70	2.45
JG0501	20	0.99	1.12	0.49	0.90
JG0502	39	0.96	1.13	0.67	0.83
JG0601	23	0.24	0.27	0.22	0.22
JG0701	29	0.12	0.04	0.09	0.04
JG0801	25	0.20	0.14	0.07	0.04
JG0901	29	0.18	0.17	0.16	0.08
JG1001	24	0.07	0.08	0.14	0.07
JN0101	20	20.62	23.91	19.39	24.73
JN0102	44*	20.29	26.17	19.67	26.17
JN0103	58	20.13	26.50	18.96	27.09
JN0104	44	20.70	26.56	20.06	26.79
JN0105	12	19.64	20.47	18.78	20.15
JN0201	12	16.41	18.64	16.46	18.81
JN0202	14	17.21	19.72	17.15	20.15
JN0203	23	18.69	22.51	17.40	22.29
JN0204	50*	17.51	25.37	16.77	26.50
JN0205	22	16.69	22.45	15.47	22.48
JN0301	4	10.83	10.83	10.02	10.02
JN0302	18	12.22	14.59	11.86	15.13
JN0303	32	11.64	18.44	11.55	20.01
JN0304	4	12.08	12.08	12.27	12.27
JN0401	24	4.59	4.92	3.97	4.60
JN0501	14	3.42	3.79	2.97	3.67
JN0502	31	3.72	6.82	3.38	7.40

Table B-4. Average winter salinities, Cont'd.

Station	Base Condition Depth (ft. below msl)*	Base Condition Salinity (ppt)		Plan Condition Salinity (ppt)	
		Surface	Bottom	Surface	Bottom
JN0601	10	2.00	1.95	1.88	1.88
JN0602	10	1.64	1.73	1.49	1.71
JN0603	28	1.28	1.52	1.67	1.54
JN0701	4	1.69	1.69	1.47	1.47
JN0801	25	0.56	0.57	0.50	0.56
JN0802	12	0.49	0.50	0.38	0.41
JN0803	24	0.31	0.17	0.44	0.36
LF0101	4	17.55	17.55	17.19	17.19
LF0201	16	15.82	17.46	14.98	16.80
LF0301	10	16.96	17.81	16.42	18.18
LH0001	20	25.09	29.66	24.72	29.07
LS0001	18	22.39	25.52	21.55	25.09
LS0002	23	23.71	26.73	22.83	25.97
LS0003	24	23.73	28.28	23.16	27.48
LS0004	18	24.56	27.23	23.79	26.67
MB0102	20	21.45	23.32	21.24	23.54
NN0001	50*	19.98	25.96	19.83	25.71
NS0101	17	15.30	17.04	14.61	17.39
NS0102	4	15.46	15.46	15.37	15.37
NS0201	20	14.11	15.07	13.57	14.65
NS0301	19	13.52	13.99	12.91	14.09
NS0401	10	12.13	13.14	11.05	10.93
NS0501	4	6.67	6.67	6.43	6.43
PQ0101	10	21.06	22.30	20.84	22.17
RS0003	52	20.37	25.73	20.17	25.69
TS0001	49	26.64	31.64	26.54	31.82
TS0002	49*	26.29	31.92	27.19	31.49
TS0003	49*	25.38	31.53	25.16	31.40
TS0004	49*	23.70	30.99	23.57	31.06
TS0005	49*	22.09	30.38	22.40	31.00
WB0101	14	17.09	21.56	16.56	21.44
WB0201	16	16.28	19.39	15.82	19.23
WO0101	10	20.41	23.46	20.16	23.88
YG0101	34	20.64	24.27	20.35	23.95
YG0102	54	21.29	25.93	21.29	25.90
YG0201	59	21.00	25.23	20.33	25.08
YS0001	49	25.56	30.48	25.51	30.43
YS0002	49	24.36	28.74	24.56	29.37
YS0003	49	23.58	27.84	23.30	27.93
YS0004	49	21.97	27.73	22.56	27.99
YS0005	52	22.52	28.42	22.49	28.57
SA0	60	25.78	31.49	26.28	32.02
SB0	30	24.78	27.39	25.13	28.12

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4-86
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